DECEMBER, 1958

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON SWI

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VOL. 190 PART 4

Principal Contents

New Methods in Pig-iron Manufacture
by A. N. Pochaisneca 337

Primitive Iron-smelting Technique
by E. J. Wynne and R. F. Tylecote 339

The Imatra Thermit Hot-topping Process
by A. I. Aitken et al. 349

Methods for Assessing Non-metallic Inclusions in Steel
by T. R. Allmand 359

Development of Methods for Isolating Structural Constituents in Steel
by W. Koch and H. Sundermann 373

Determination of Hydrogen in Steel by Carrier-gas Technique *by C. E. A. Shanahan and F. Cooke* 381

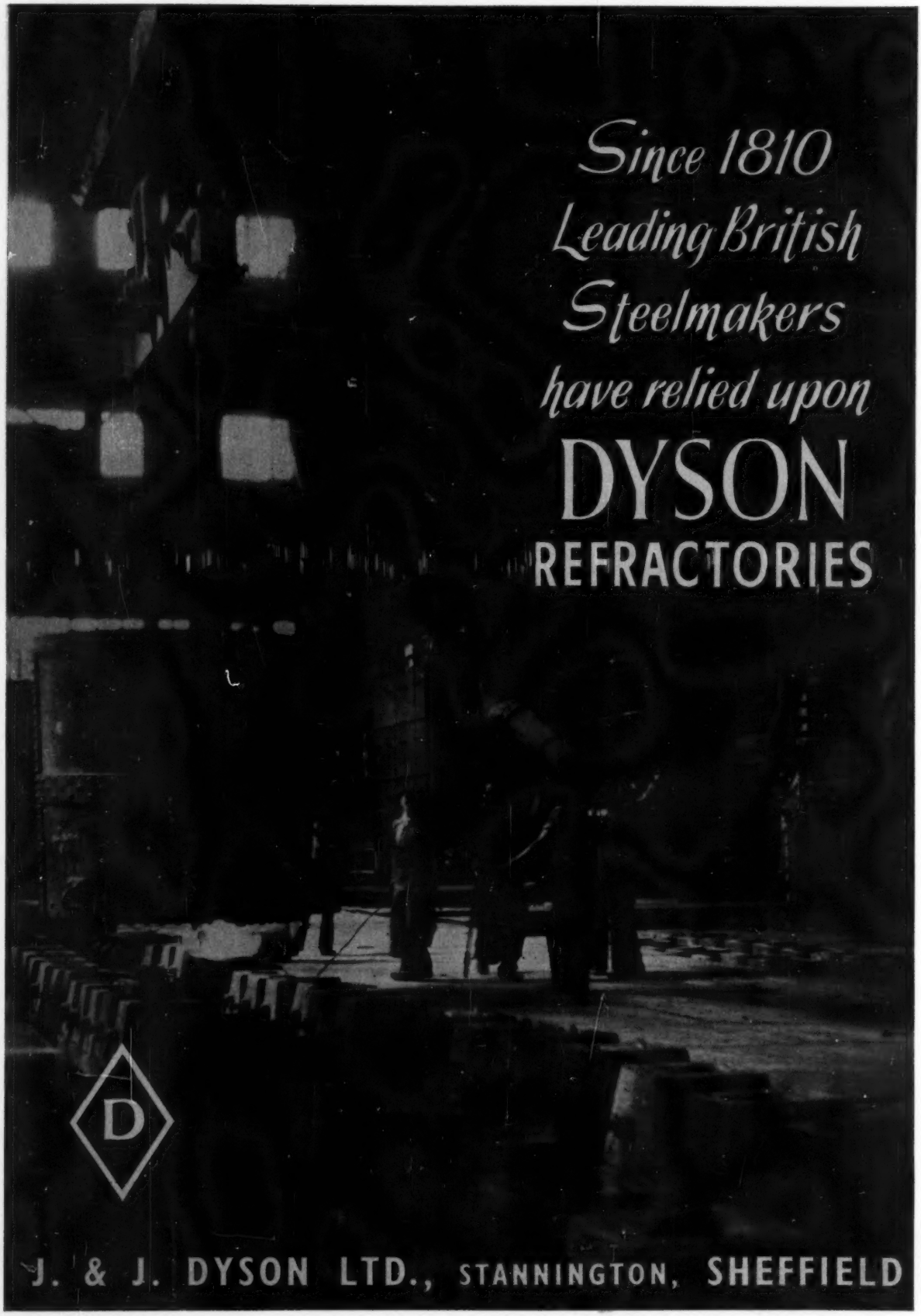
Kinetics of Bainite Formation in Plain Carbon Steel
by P. Vasudevan et al. 386

Survey of Forging Manipulators and their Applications
by P. L. Lillyachite 394

Vacuum-melting of Steels
by H. C. Child and G. T. Harris 414

News 432 Abstracts 437

A full list of contents is given on the Title Page (see page 67, Advertisement Section)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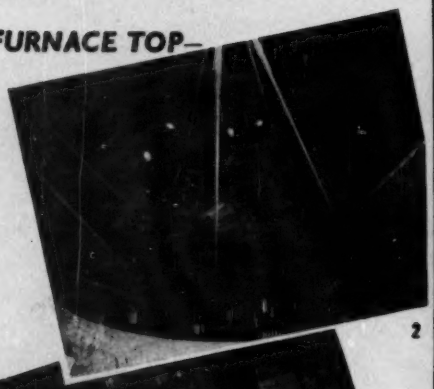

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—TO FURNACE BOTTOM

1

Scenes of operations at No. 1 Blast Furnace
(photos by permission of John Summers & Sons Ltd., Shotton)

Furnace blown out	23rd April 1958
Demolition commenced	26th April 1958
Demolition completed	13th May 1958

TOTAL TIME wrecking burden, lining, hearth and bear
18 DAYS
(contract carried out in association with Salem Engineering Co. Ltd.)

1 *'Lumpy going'—half-way down hearth.*
2 *Men removing throat armour.*
3 *Cat Traxcavator commencing digging, Cast House Floor Level.*
4 *The two 'cats' meet—final 'break through'.*

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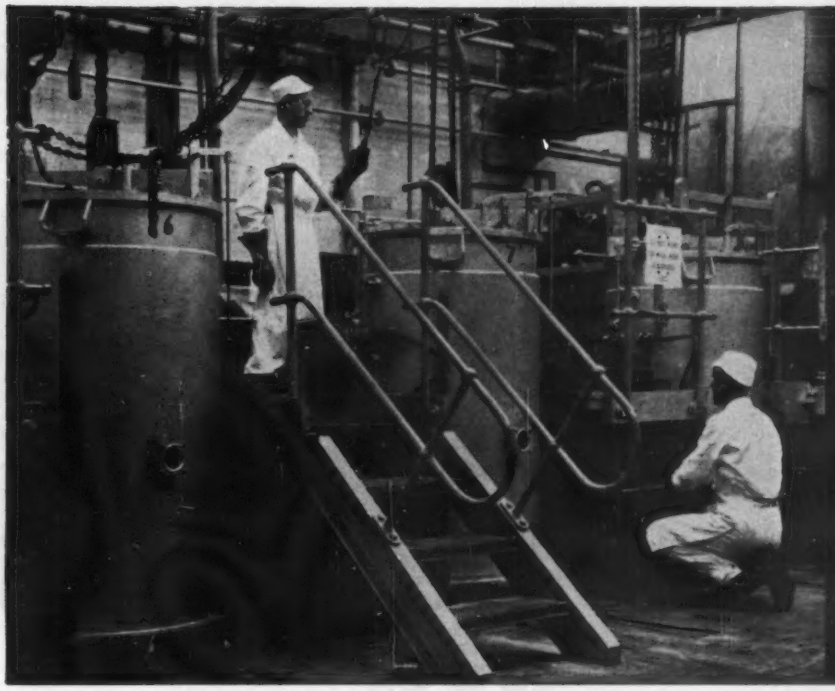

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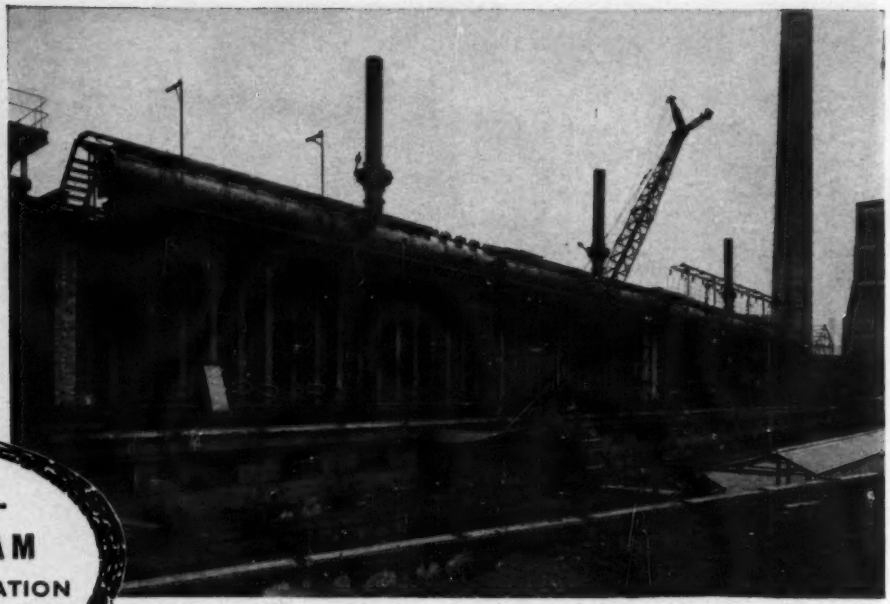

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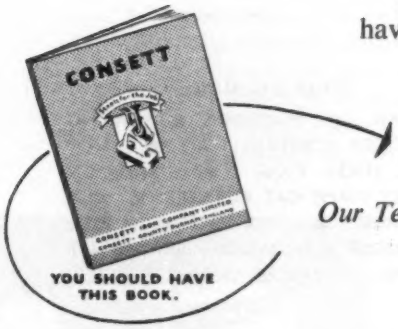

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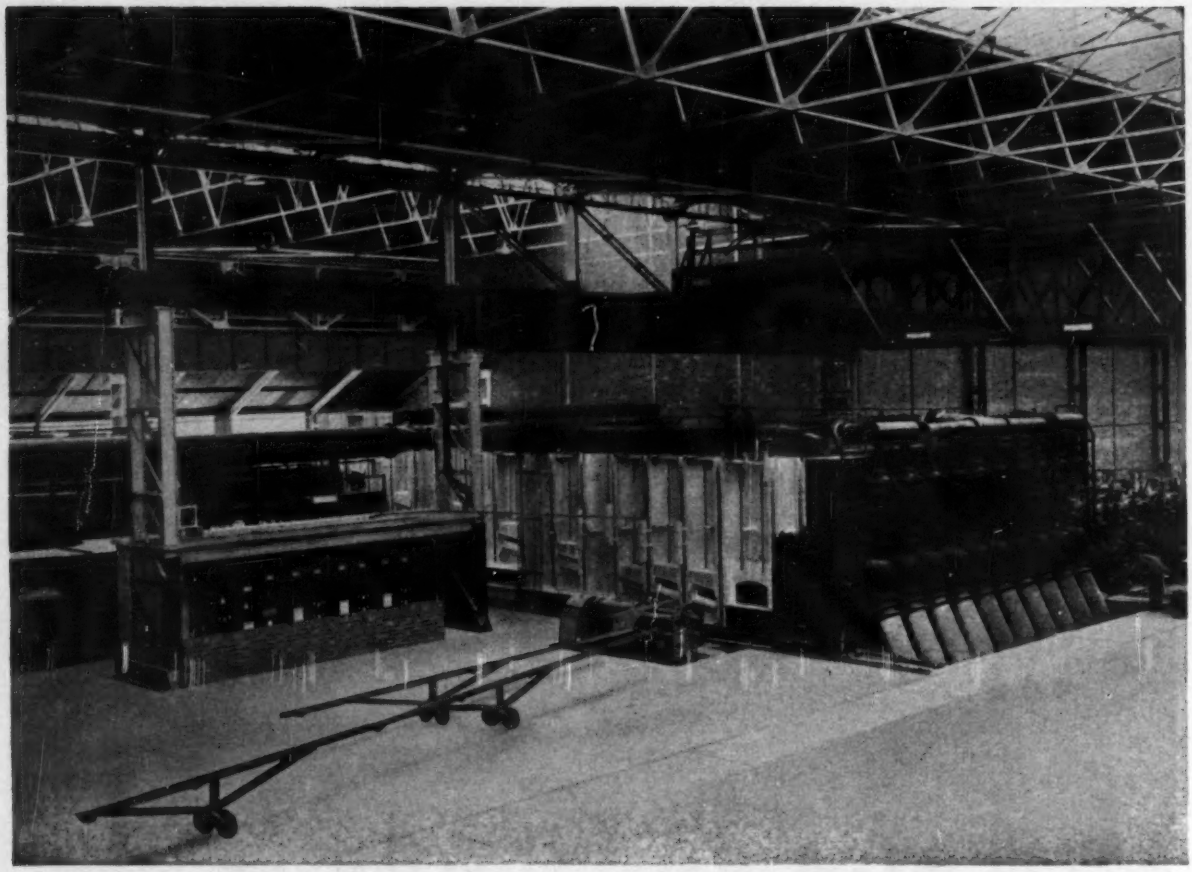

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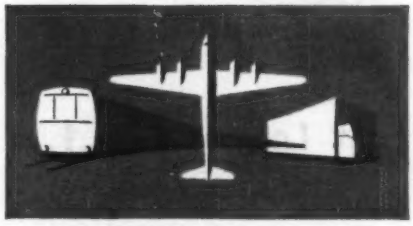

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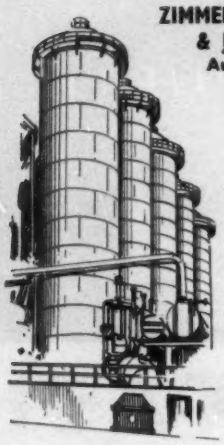
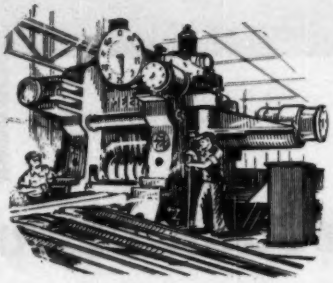
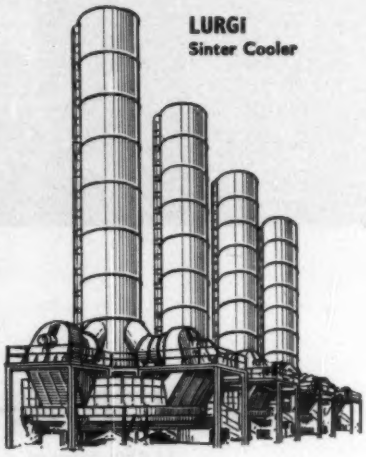


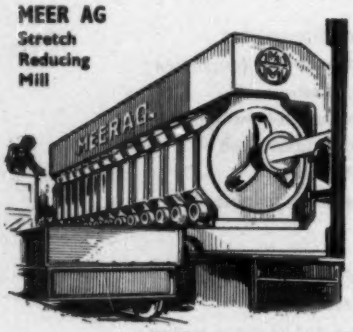
MEER AG Plug Mill



LURGI Sinter Cooler



MEER AG Stretch Reducing Mill



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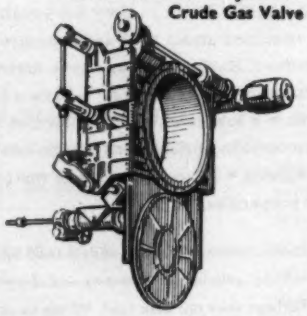
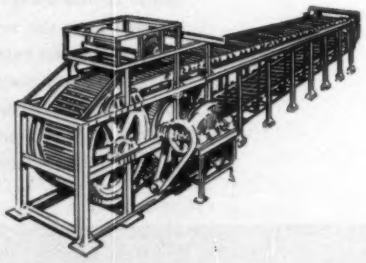


LURGI Sintering Machine



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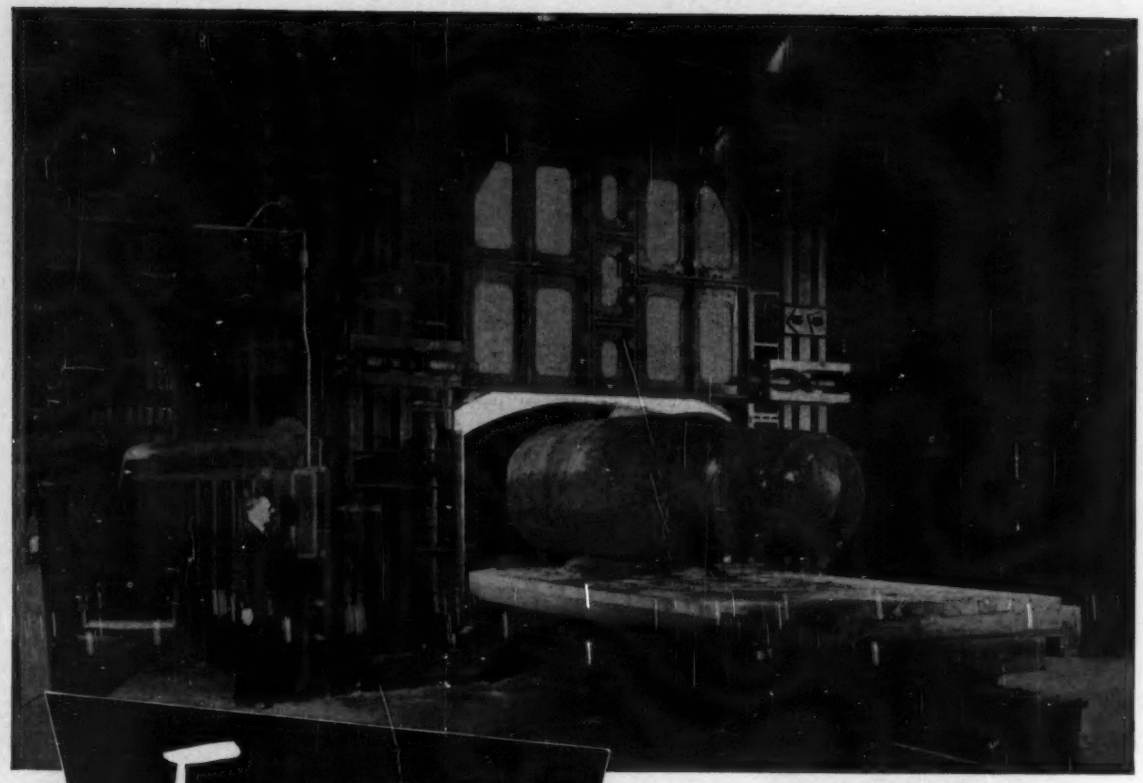

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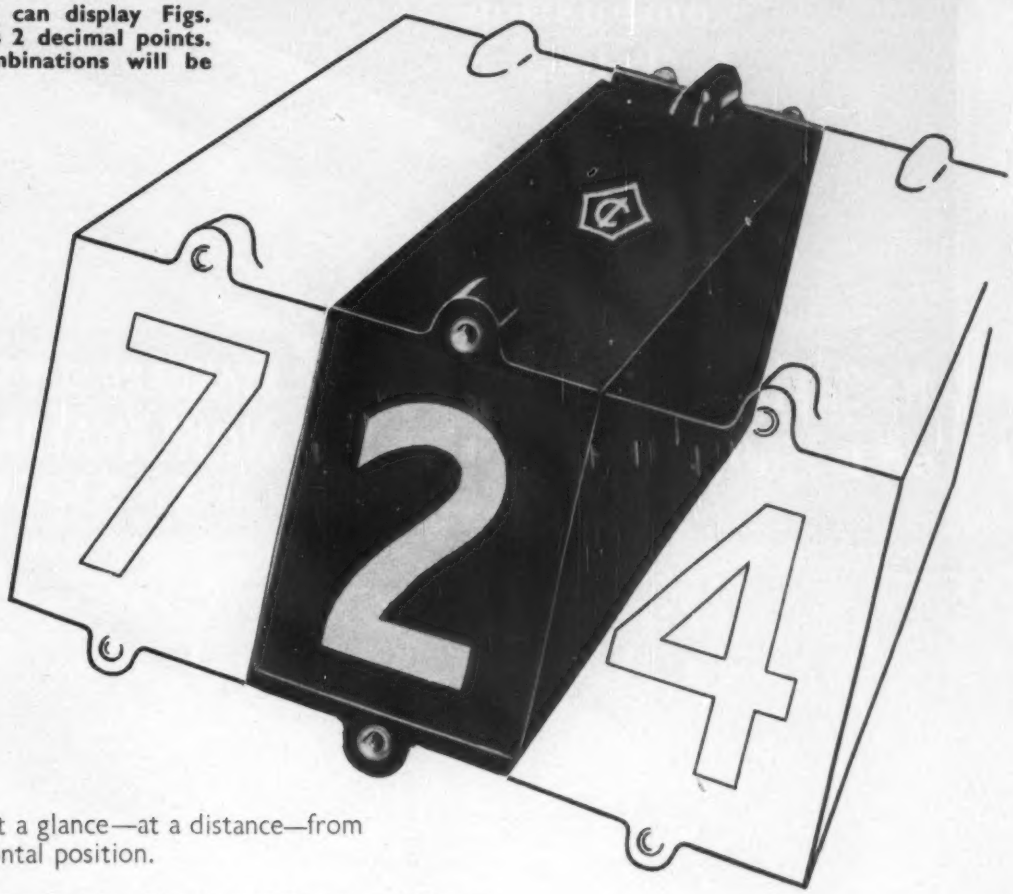

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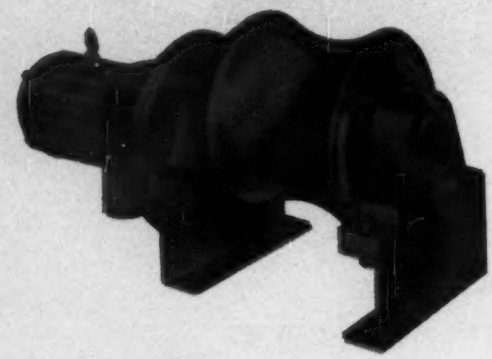

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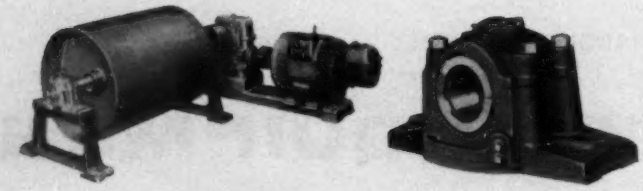
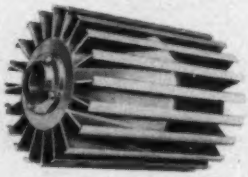


Conveyor Drives. Publication 853.

Plummer Blocks, plain, ball or roller bearings. Publication 5734



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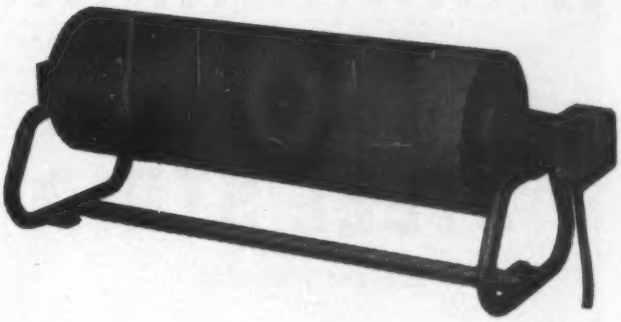
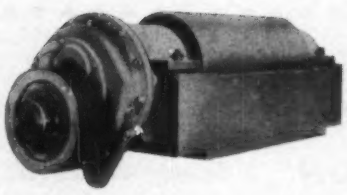


Shaft Mounted Gear Units for Conveyor Drives. Publication 157.



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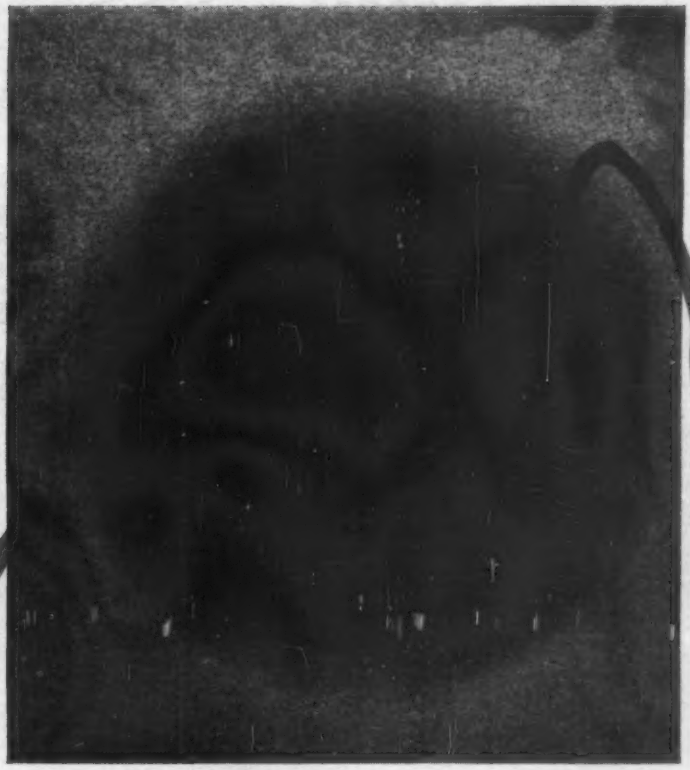

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Electrical Aids in Industry — *Data Sheet* **No. 2**

Induction Heating-1

Electro-magnetic induction was discovered by Faraday and used by him to evolve the electric motor. In some cases, induction can be a nuisance by causing heat losses to arise from induced eddy currents in nearby pieces of metal, but in industry today those heat losses are being turned to good account as a method of metal heating.

Induction heating produces heat only in the work piece. This is a fascinating and spectacular process which has the additional merit of being extremely effective. An important feature of induction heating is that it gives rapid temperature rise with no time lag, starting being instantaneous. Perhaps its greatest advantages are that it can be used in automatic processes and does not demand skilled labour.

Induction heating can deal efficiently with all the applications outlined below, and including metal melting, preheating and stress relieving, surface hardening, heating of large components, preheating of steel tubes for manipulating, heating for shrinking, for forging and extrusion, as well as for the heating of vessels. There are various methods of applying it, the method to be used being dictated by the application.

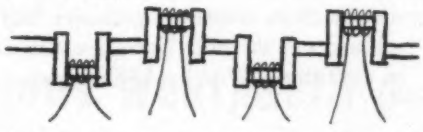
Technical details relating to the choice and use of individual types of induction heating will be set out in a subsequent data sheet.

Metal melting

The oldest and largest application of induction heating lies in the melting of metals. The outstanding advantages are: freedom from deleterious gases and products of combustion and other contaminants, rapid speed of melting, low running costs, improved working conditions and reduced metal loss.

Metallurgical processes

This covers a large variety of processes which may be basically divided into surface heating and through heating. Most processes fall into the former category and are used for the purpose of



skin hardening. They include the treatment of such components as: pins, camshafts, crankshafts, rollers, cylinder liners, gear teeth, rocker arms and shafts and valve stems.

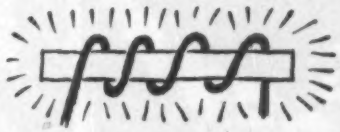
5857

Through Heating

When the current in an induction coil is maintained for a longer period it results in the heat engendered in the work piece penetrating to a greater depth and eventually throughout the piece. It is largely used for the heating of slugs and billets, for upsetting and upset forging, flanging and nosing, shearing and forging and bolt blanks for heading.

Annealing

Induction heating is the ideal method of altering the character of metals for a special purpose. Annealing and its related process of tempering, normalising and stress relieving are prominent in



this category. In the case of annealing, one feature of the treatment is that it can be localised, while induction tempering can do in one minute what would require half-an-hour or more with conventional furnace heating.

Brazing, soldering and welding

Brazing and soldering by induction are the quickest and cleanest methods of joining metals together, and it is often beneficial to re-design the parts so that the fullest advantage can be taken of induction heating. Brazing can be used in the case of: carbide inserts for tools, tips for rock drills, parts for universal joints, etc., while the many applications of soldering are well-known. It was not until well into the present century that the age-old craft of welding became a positive aid to greater productivity. Induction welding produces a good, clean weld because oxidation is almost absent.

Miscellaneous Application

Induction heating can be profitably used for a large variety of purposes, including the fusion and hot pressing of powders, heating *in vacuo*, gas determination in metals, fusion of glass, chemical work and many other processes.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association.

Excellent reference books are available on electricity and productivity (8/6 each or 9/- post free)—"Induction and Dielectric Heating" is an example.

E.D.A. also have available on free loan a series of films on the industrial use of electricity. Ask for a catalogue.

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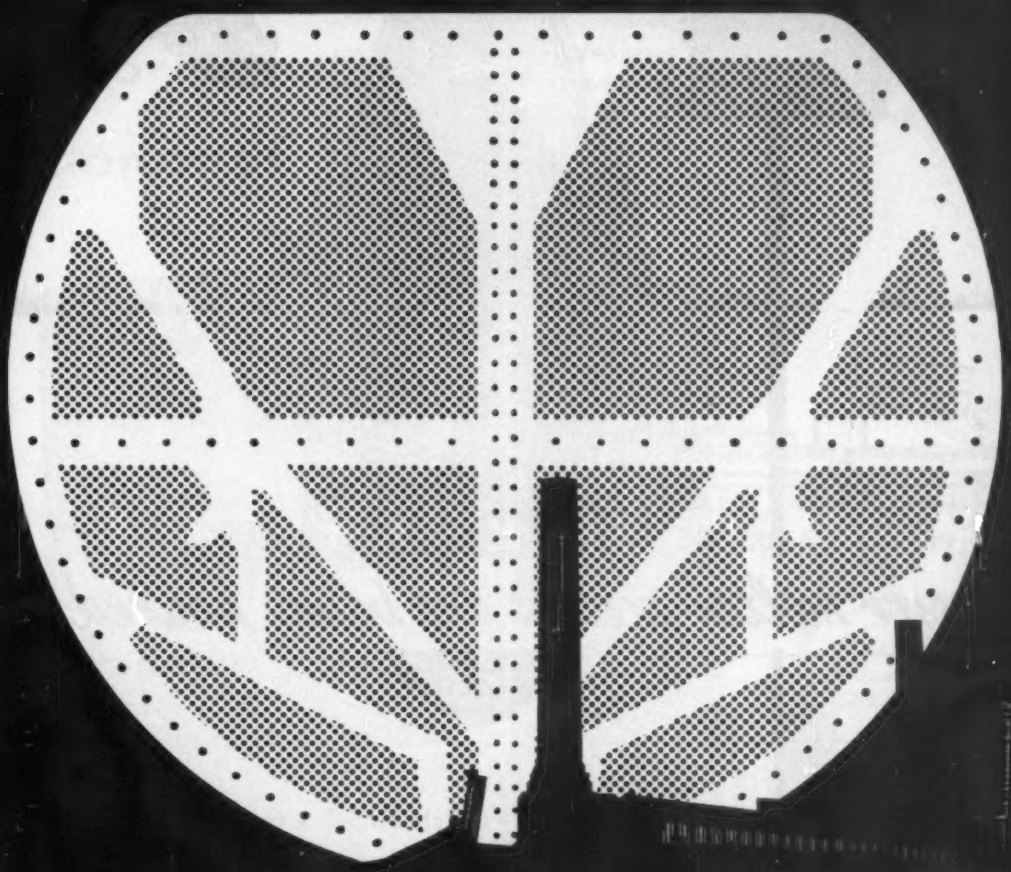

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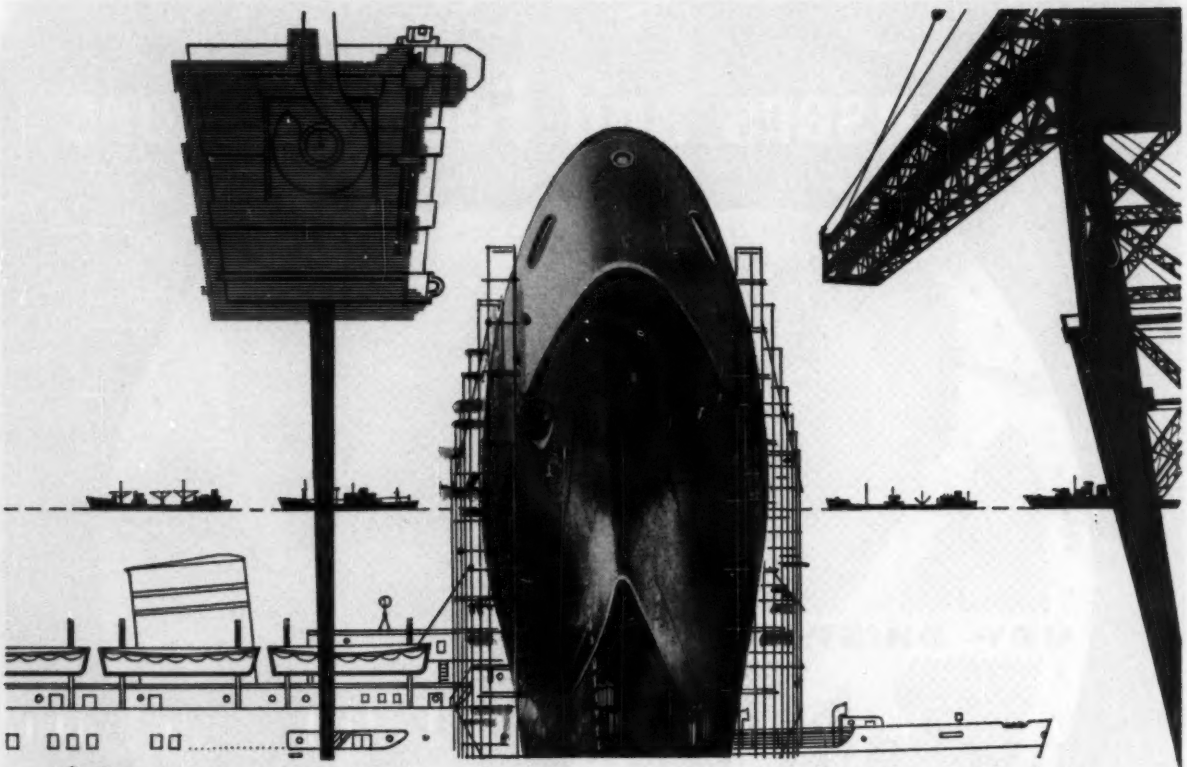

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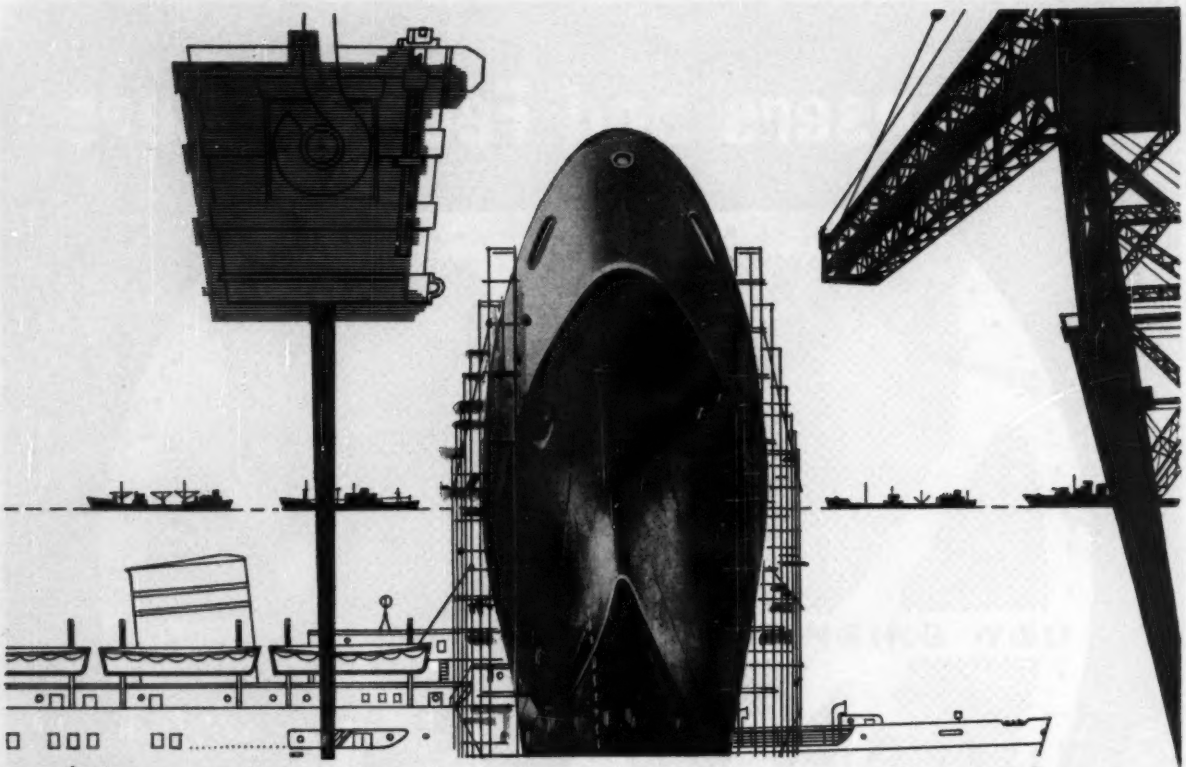

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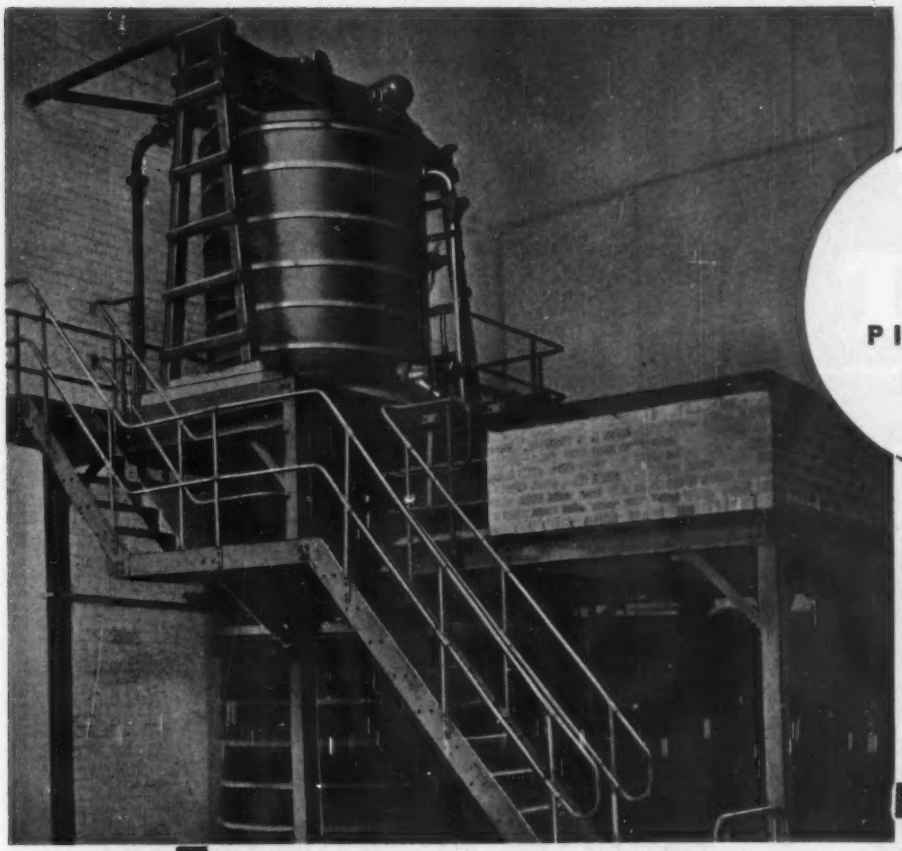

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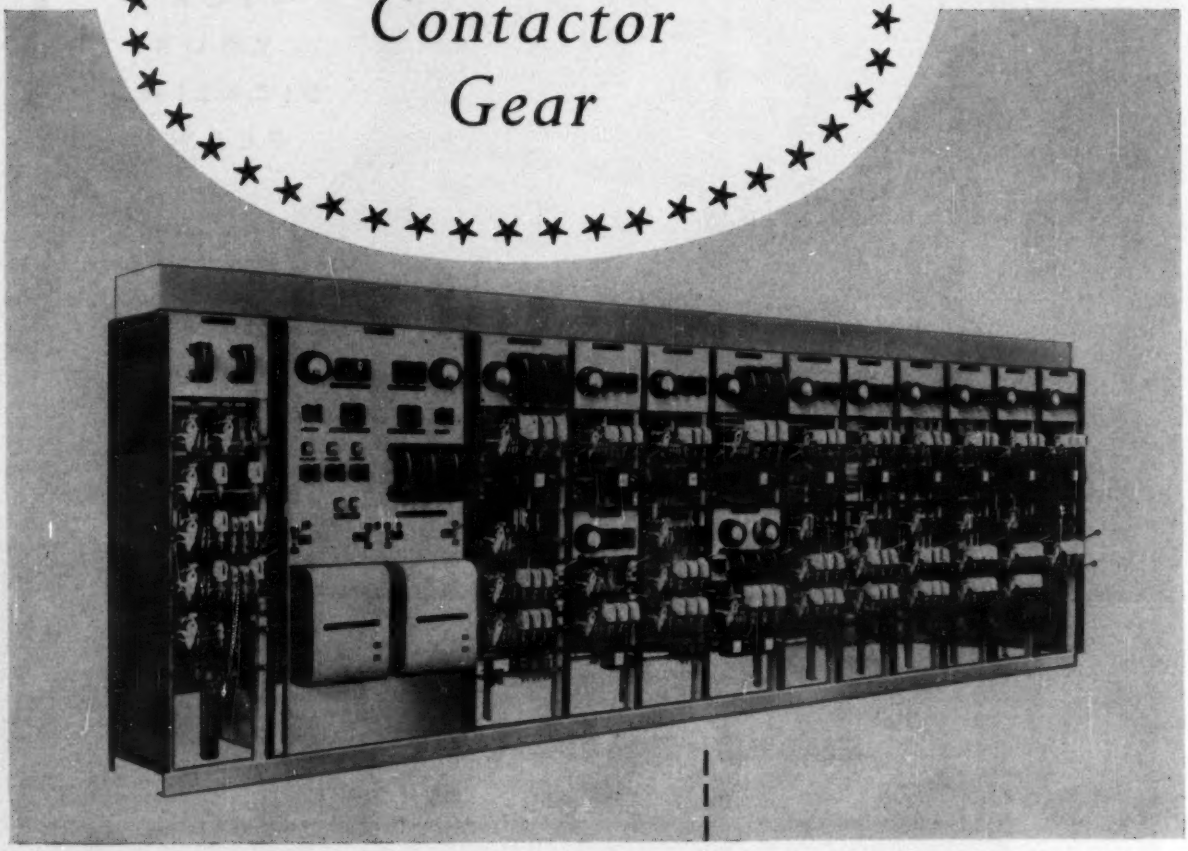

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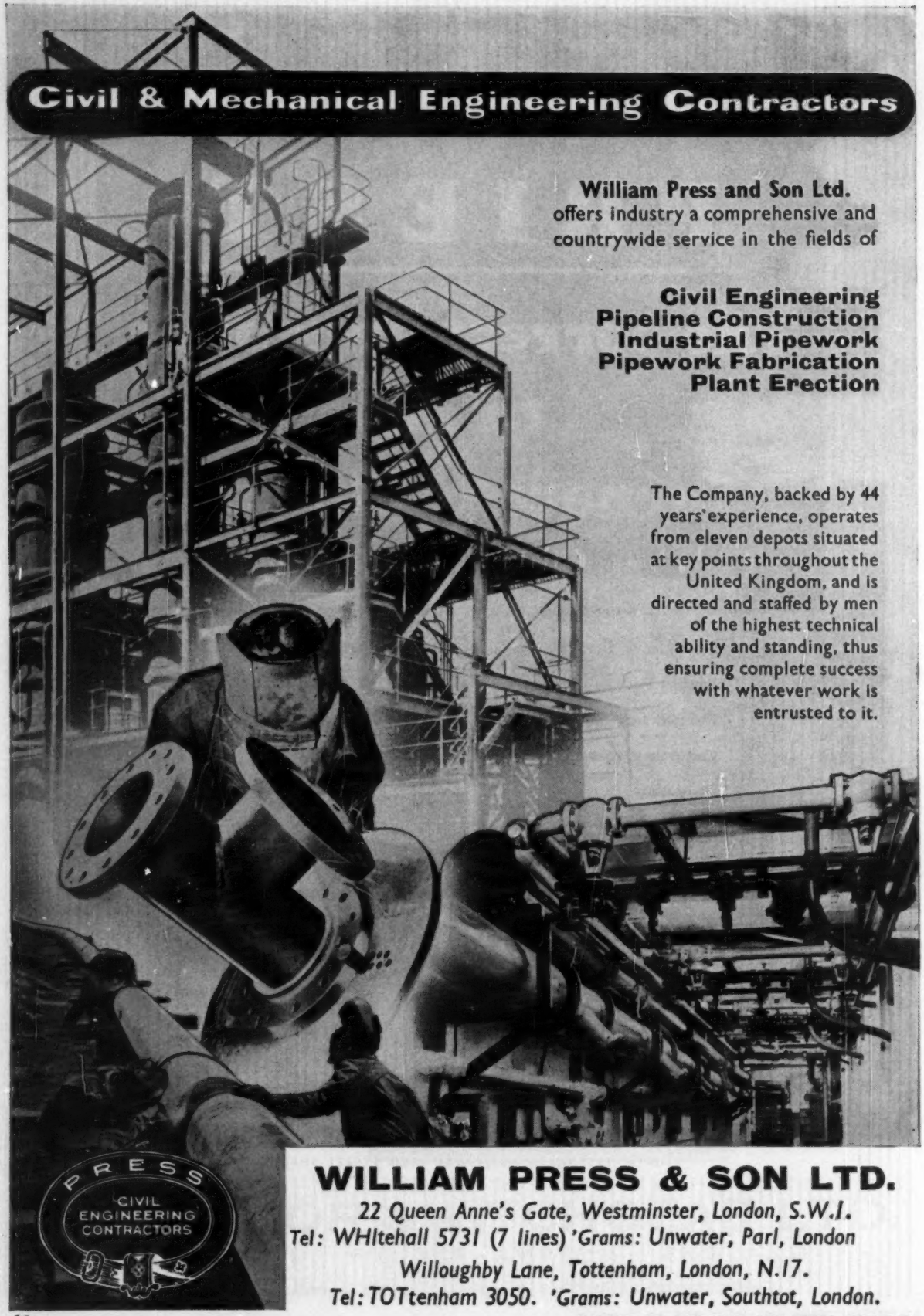
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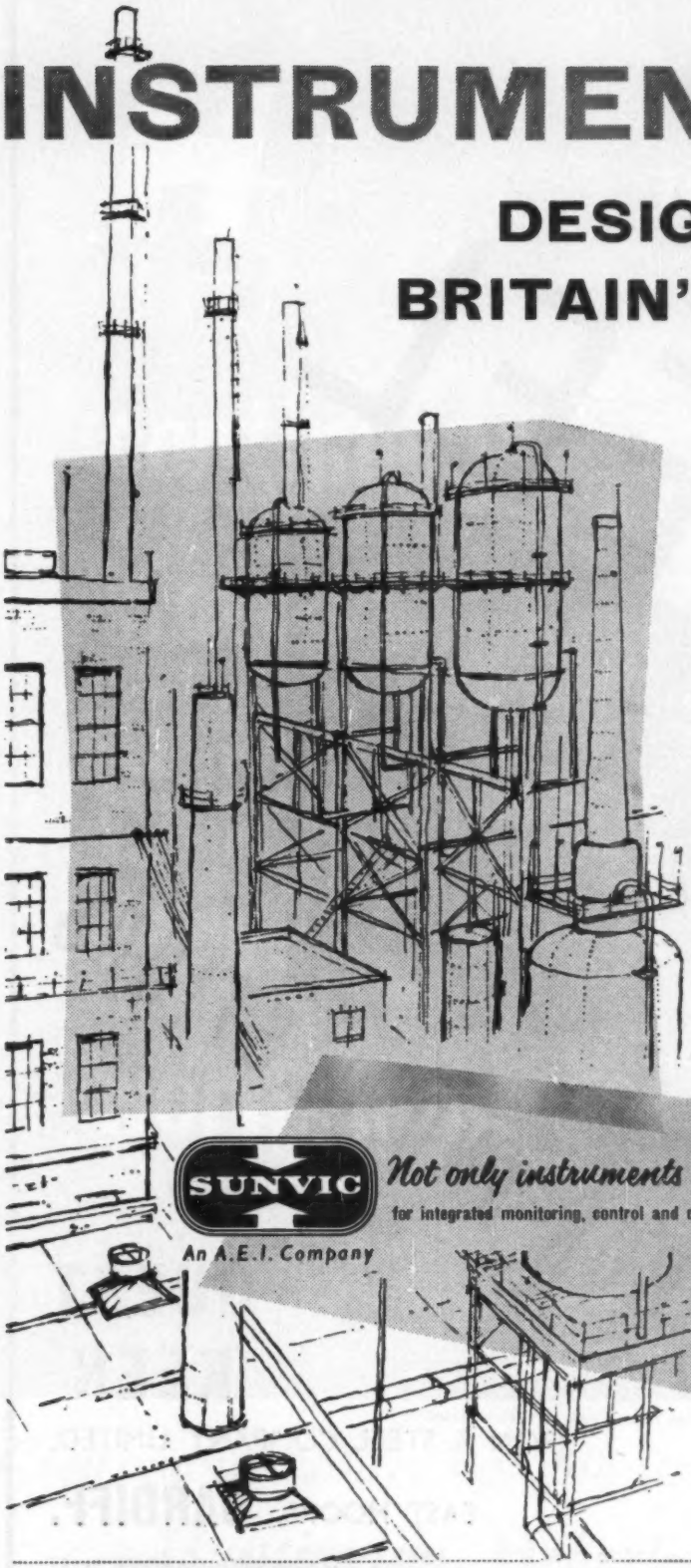

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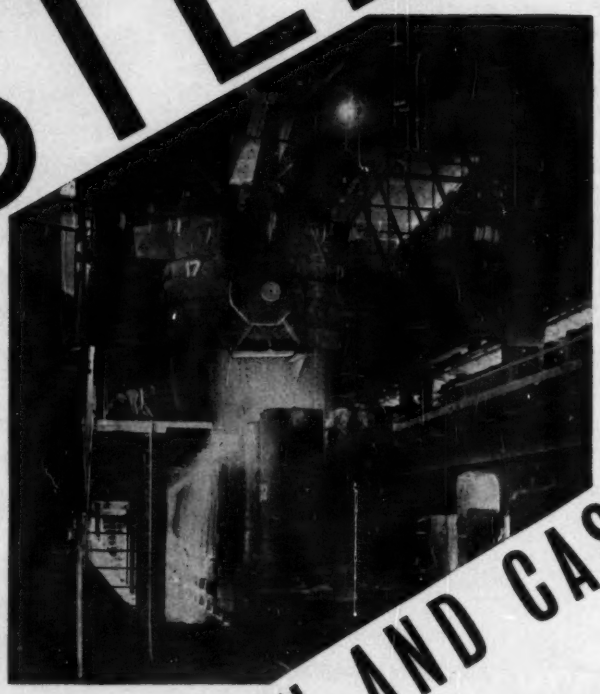

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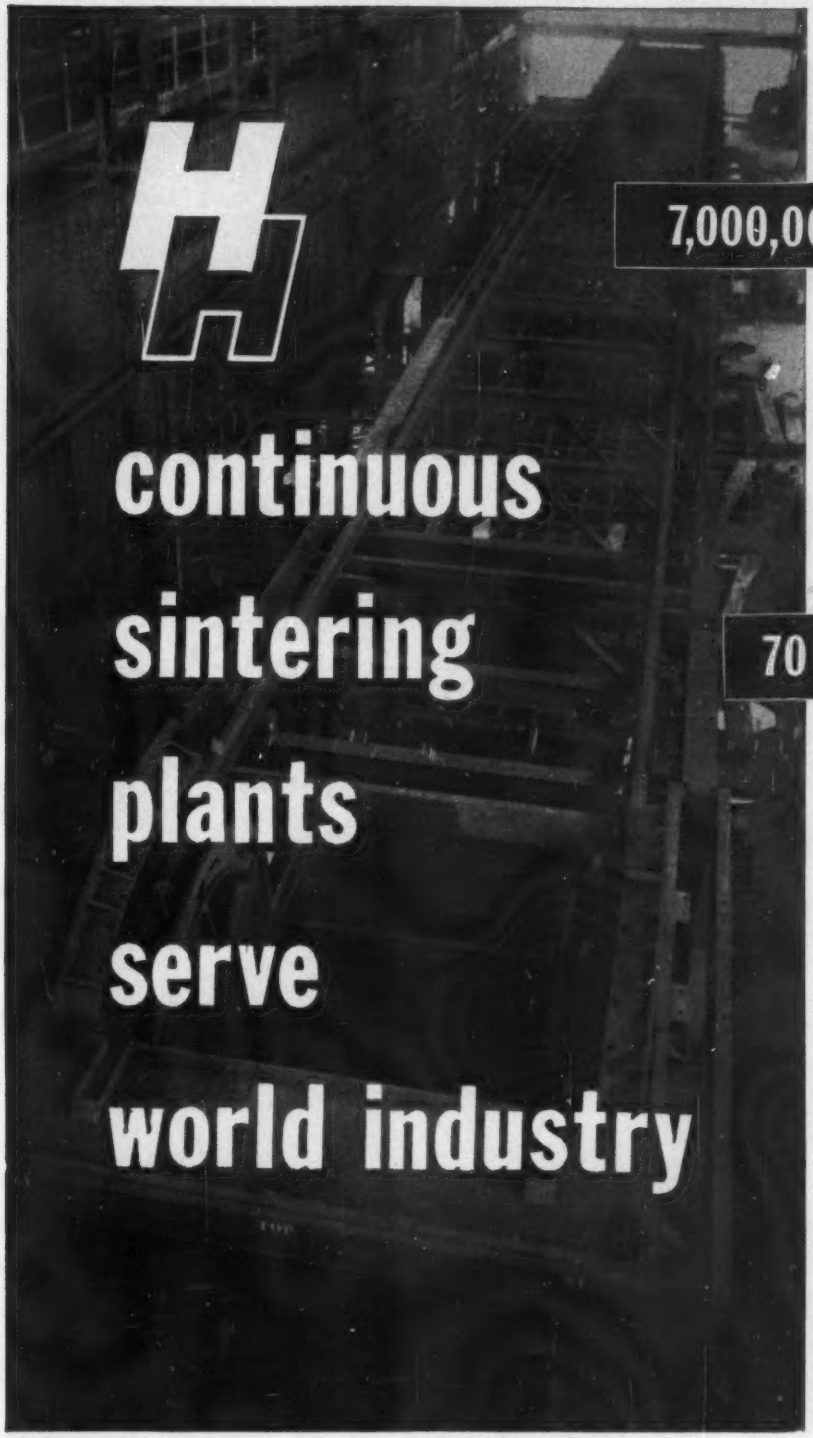

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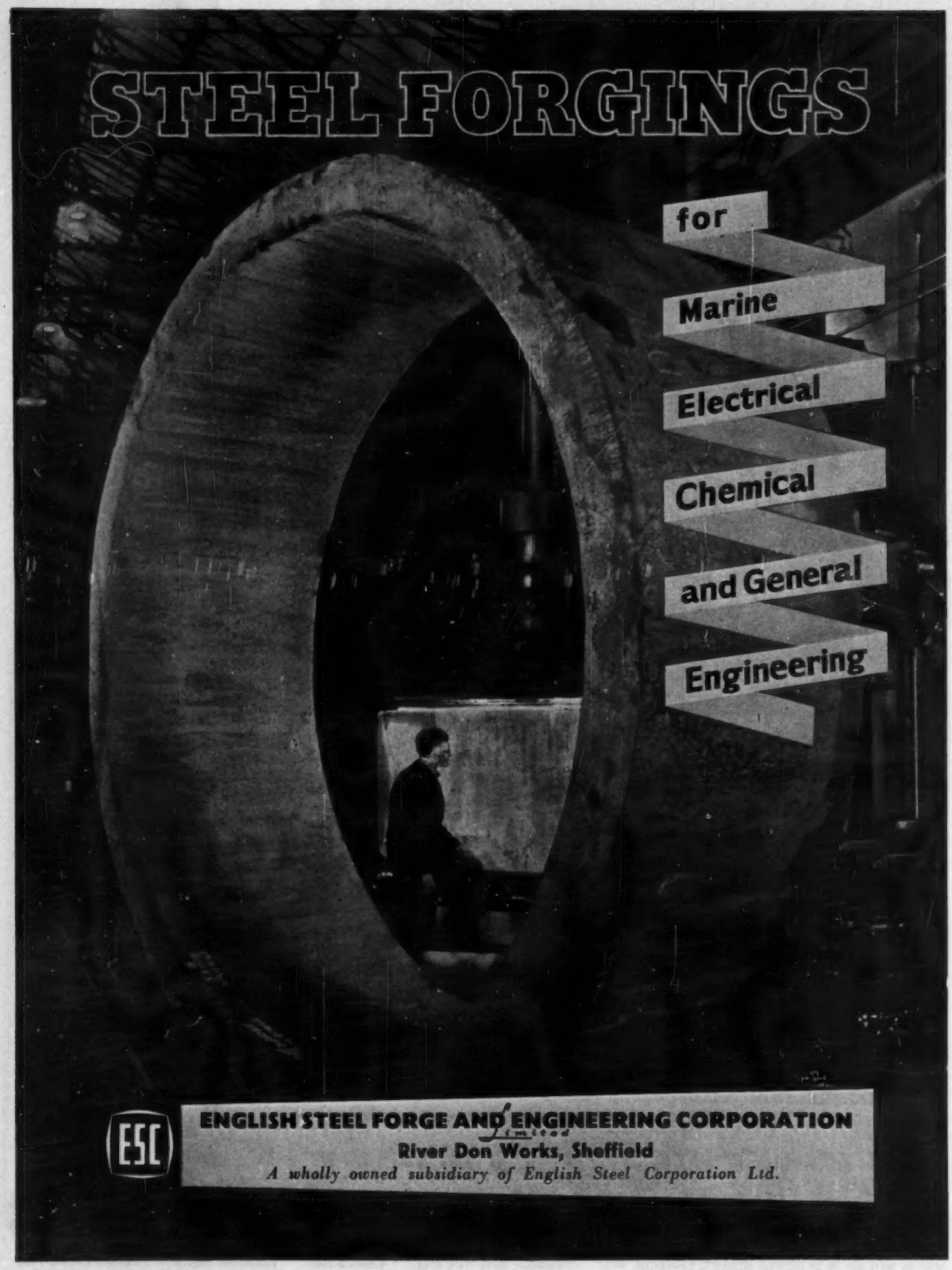
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NORMANBY PARK STEELWORKS. Tel.: SCUNTHORPE 2271

BASIC OPEN HEARTH STEEL PRODUCERS

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CARBON STEELS UP TO ·75
DEEP STAMPING AND RIMMING
SILICON AND SILICO-MANGANESE
FREECUTTING
LEAD-BEARING

STRIPPING BAY

MORGAN MILL FLYING SHEARS

SIZES:

BLOOMS	5″ UP TO 9″
BILLETS	2″, 2¼″, 2½″, 3″, 3½″ & 4″
SLABS	5″ TO 16″ WIDE X 1¾″ TO 2½″ THICK
SHEETBARS	12″ X ¼″ TO ¾″

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ROUNDS	5G. TO $\frac{9}{16}$″
SQUARES	6G. TO $\frac{7}{16}$″
RODS IN 500LB. COILS	(I/D 28″ O/D 36″)

ROD CONVEYOR

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Hot and Cold Rolling Mills
Rolls for Hot and Cold Rolling
Roll Lathes
Hot and Cold Shears
Hot Saws and Reelers
Steelworks Plant and Auxiliaries.

Photographs from our Ecclesfield Works of large Housings for a Blooming and Slabbing Mill in the course of manufacture.

THE BRIGHTSIDE FOUNDRY & ENGINEERING CO. LTD.
G.P.O. BOX 118 SHEFFIELD 1.

JOSEPH ADAMSON
Waste Heat Boilers

JAC

The Joseph Adamson Waste Heat Boiler is designed to make efficient use of the waste gases leaving open-hearth furnaces, reheating furnaces, soaking pits, gas retorts, etc.

The straight-through fire tubes have a high ratio of length to bore, giving about 90% tube efficiency and providing a large area of heating surface in a comparatively small space. Brickwork setting is not required and air infiltration is thus avoided.

A feature of Joseph Adamson Waste Heat Boilers is that a special cleaning device can be provided in the outlet chamber to allow the tubes to be cleaned while the boiler is at work.

JOSEPH ADAMSON & CO. LTD.
P.O. BOX 4 · HYDE CHESHIRE
in association with
Adamson Alliance Co. Ltd., 165 Fenchurch St., London, E.C.3
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THE ADAMSON GROUP

JA. 11

SCHLOEMANN

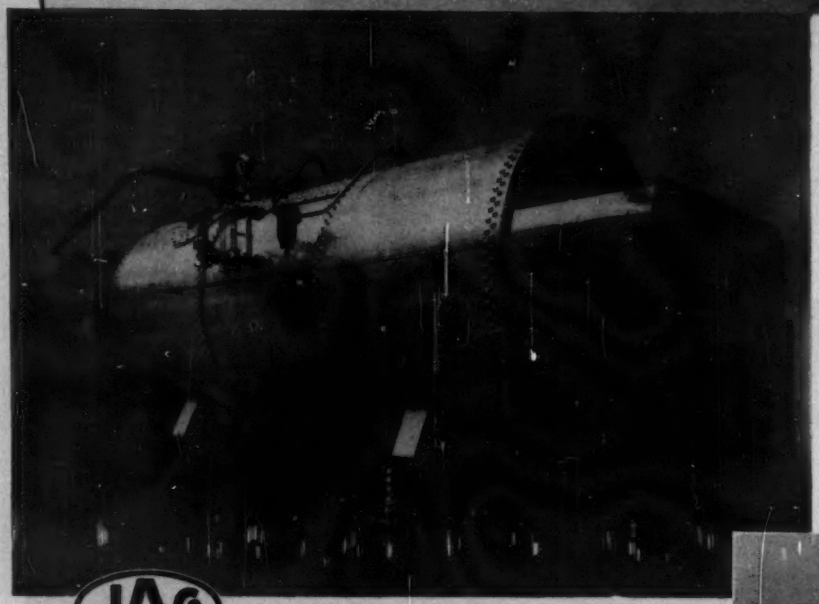
500 ton quick acting forging press during automatic planishing of a square shaft. In order to demonstrate the easy accessibility of the cylinders and stuffing boxes, the protective cover has been removed.

SCHLOEMANN open-die forging presses with a power of up to 15,000 tons have proved their efficiency on four continents. Recently SCHLOEMANN have developed small quick acting forging presses of welded steel design with powers of 500 and 1,000 tons. These small presses incorporate a number of important innovations which contribute greatly to maximum efficiency and economy. *Please ask for leaflets 35/4e and 35/5e*

DOLLERY & PALMER LTD · 54, Victoria Street LONDON SW 1 · Lydgate Lane SHEFFIELD 10

HOT AND COLD ROLLING MILLS • COUNTERBLOW HAMMERS • HYDRAULIC PRESSES

JOSEPH ADAMSON
Waste Heat Boilers



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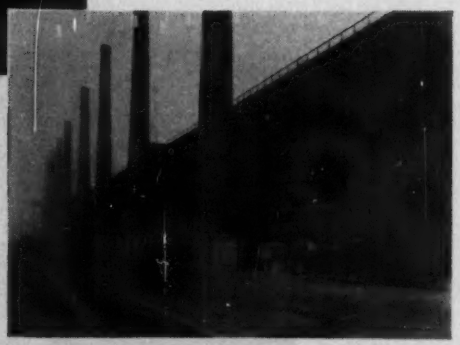

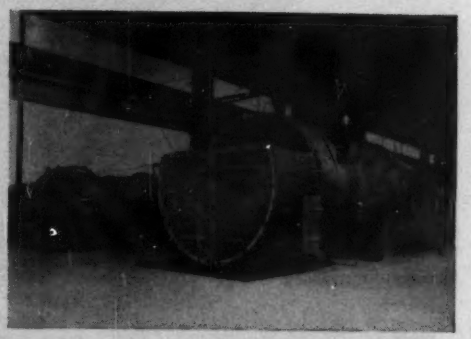

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Illustration shows a 15″ and 37″ x 60″ Reversing Four-high Cold Rolling Mill for soft, and alloy steel strip up to 50″ wide. Maximum rolling speed 1,200ft./min.

Photograph by courtesy of Messrs. Richard Thomas & Baldwins Ltd.

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HEMISPHERES *for universal drives*

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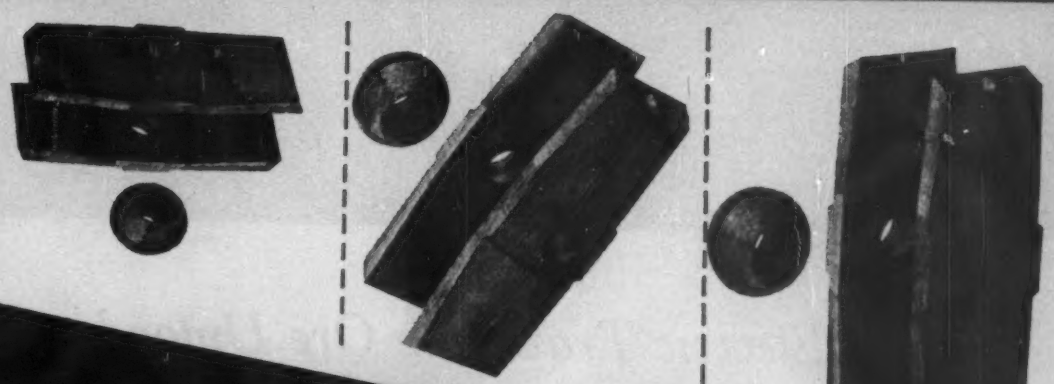

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Illustrated above are three 20 Ton Electric Travelling Ore Unloaders, built by Arrol at General Terminus Quay, Glasgow, for Messrs. Colvilles Limited. The machines have an outreach of 68 feet from the waterside rail and a combined maximum handling capacity of 1,800 tons of ore per hour, discharging on to a conveyor system.

Cranes and other Mechanical Handling Plant; all types of Steel Framed Buildings; Fixed and Opening Bridges; Dock Gates; Sliding and Floating Caissons; Compressed Air Locks; Hydraulic Machinery; Pipe Lines, Surge Tanks, Sluices and other equipment for Hydro-Electric Projects.

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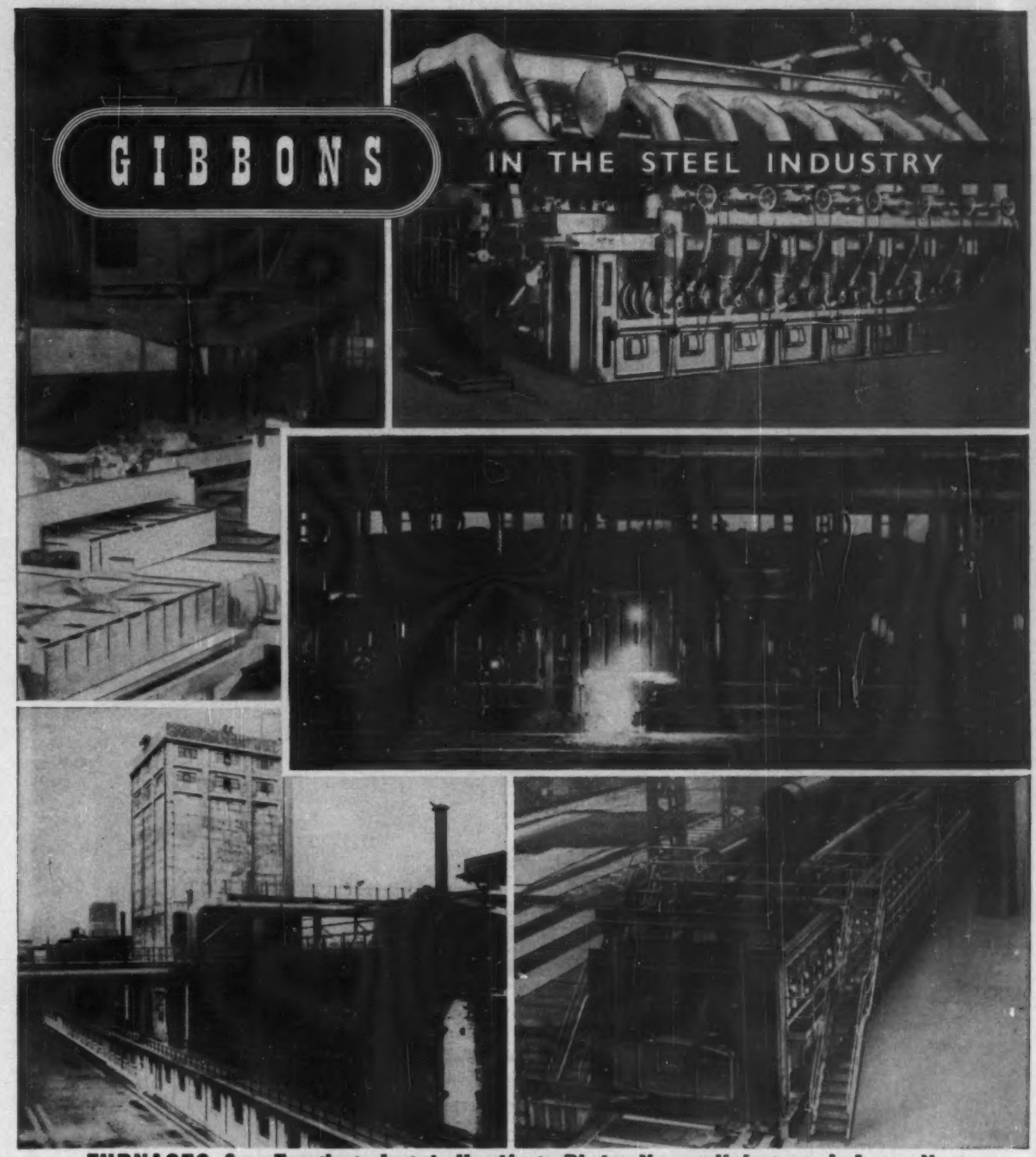
Arrol



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Modern control gear for the Metal Industries

Photograph by permission of Richard Thomas and Baldwins.

An installation incorporating 300 ft. of 'ENGLISH ELECTRIC' control boards for the operation of the new continuous galvanising line at Richard Thomas and Baldwins' Ebbw Vale Works.

The future of the Metal Industries depends more than ever on the up-to-date design of control gear. 'ENGLISH ELECTRIC' have developed power and control schemes for leading rolling mills throughout the world for more than half a century.

Still pioneering today, the Company's engineers offer new techniques including:

Fully automatic programming for hot reversing mills
Automatic gauge control and slow-down for cold mills
Comprehensive control for all process lines.

If you have a problem on control gear, 'ENGLISH ELECTRIC' experience is available for its solution.

'ENGLISH ELECTRIC'

THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2
Metal Industries Division, Stafford
WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

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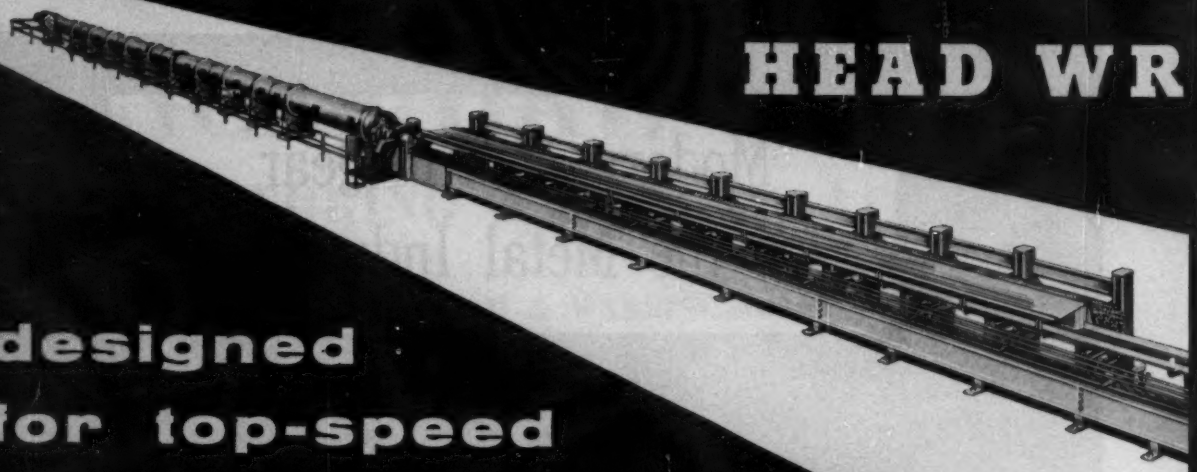

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designed
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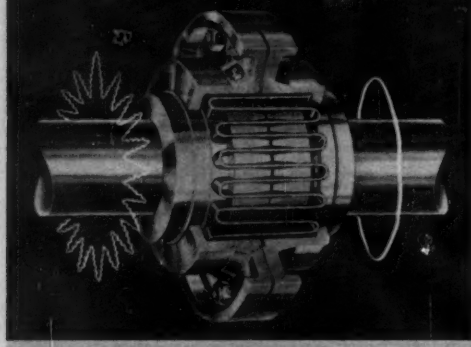
THE HEAD WRIGHTSON MACHINE CO LTD

COMMERCIAL STREET MIDDLESBROUGH

THORNABY STOCKTON LONDON JOHANNESBURG TORONTO SYDNEY CALCUTTA

The most efficient coupling obtainable



Over 30 years trouble-free service is normal with

The BIBBY *Resilient* COUPLING

Breakdowns, heavy production losses, and high maintenance costs are reduced to a minimum. Maximum outputs are ensured.

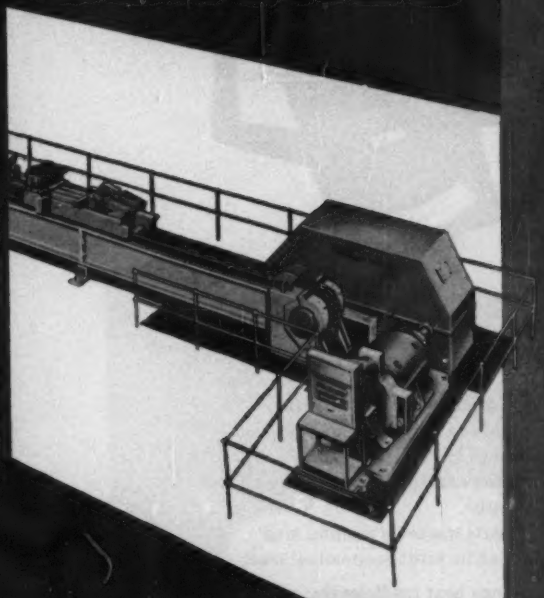
The unique resilience of Bibby Couplings protects and lengthens the life of machinery by absorbing shocks and vibrations, and accommodating unavoidable angular and parallel misalignments.

There is a Bibby Resilient Coupling for every drive.

We invite you to write, today, for our illustrated brochure.

THE WELLMAN BIBBY COMPANY LIMITED, PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1

GHTSON DRAW BENCHES



Our Automatic Multiple Draw High Speed Tube Drawbenches are equipped with the following special features:—

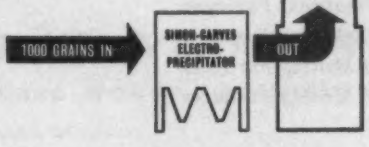
1. AUTOMATIC AIR OPERATION OF CARRIAGE HOOK AND GRIPS
2. HIGH SPEED CARRIAGE RETURN
3. AUTOMATIC ACCELERATION AND DECELERATION OF MAIN DRIVE FOR HIGH SPEED DRAWING
4. AUTOMATIC PLUG CONTROL
5. ROTARY BACKBENCH WITH MINIMUM OF WEARING PARTS
6. ELEVATING LOADING RACK WITH POWER FEED OF TUBES ON TO BACKBENCH
7. AUTOMATIC CONTROL OF PLUG LUBRICATION
8. AUTOMATIC DISCHARGE OF TUBES AFTER DRAWING
9. MULTIPLE DRAW UP TO FIVE TUBES AT ONCE

We specialise in equipment for the production of seamless tubes in both steel and non-ferrous metals, and also for bright drawn bars.

PROOF of efficiency

SIMON-CARVES PRECIPITATORS AT C.E.G.B. POWER STATIONS

STATION	UNIT	EMISSION PER 1000 GRAINS PERMITTED UNDER GUARANTEE	EMISSION PER 1000 GRAINS MEASURED DURING TESTS
HUNCOAT	No. 1	20 GRAINS	1·7 GRAINS
HUNCOAT	No. 4	25 GRAINS	1·6 GRAINS
CHADDERTON 'B'	No. 2	20 GRAINS	5·6 GRAINS
CHADDERTON 'B'	No. 4	20 GRAINS	13·3 GRAINS
FLEETWOOD	No. 2	25 GRAINS	6·4 GRAINS
FLEETWOOD	No. 3	25 GRAINS	2·7 GRAINS
HACKNEY 'B'	No. 3	15 GRAINS	9·2 GRAINS *
ROGERSTONE	No. 2	25 GRAINS	4·4 GRAINS *



Based on results achieved at M.C.R. load under official acceptance test conditions.
** Awaiting confirmation.*

HIGH EFFICIENCY ELECTRO-PRECIPITATION BY ***Simon-Carves Ltd***

STOCKPORT, ENGLAND

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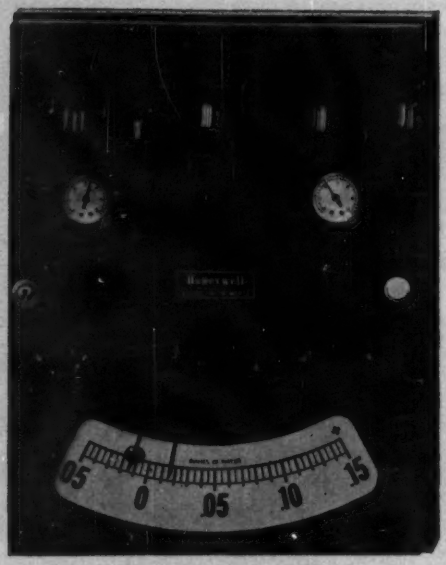
SC 199/PS

Furnace Pressure Controllers police your fuel consumption . . .



The Honeywell Furnace Pressure Controller installed on furnaces and boilers has achieved average fuel savings of 10 per cent . . . savings which often covered the instrument's cost within three months.
The instrument cuts waste by maintaining furnace pressure at its most economical level.

If pressure is low you use heat inefficiently.

Cooling draughts of air are drawn through cracks and inspection holes into the combustion chamber. Usable heat is forced up the flue to waste. Fuel consumption rises.

If pressure is high you burn fuel wastefully.

As the pressure increases inside the chamber, so does the rate at which fuel is burned. Flames damage the chamber's inner lining and penetrate deeply into the brickwork. Frequent and costly repairs are necessary.

The Honeywell Furnace Pressure Controller continuously adjusts the position of the damper to maintain a correct, fuel-saving, pressure.

WRITE NOW FOR BULLETIN 7404 — it contains full information on the advantages of Furnace Pressure Control. A free copy is available from

Honeywell Controls Ltd., Ruislip Road East, Greenford, Middlesex. (Telephone : WAXlow 2333). Sales offices in Birmingham, Manchester, Sheffield, Glasgow, Middlesbrough, Cardiff, Dublin, Belfast and throughout the world.

Typical Applications

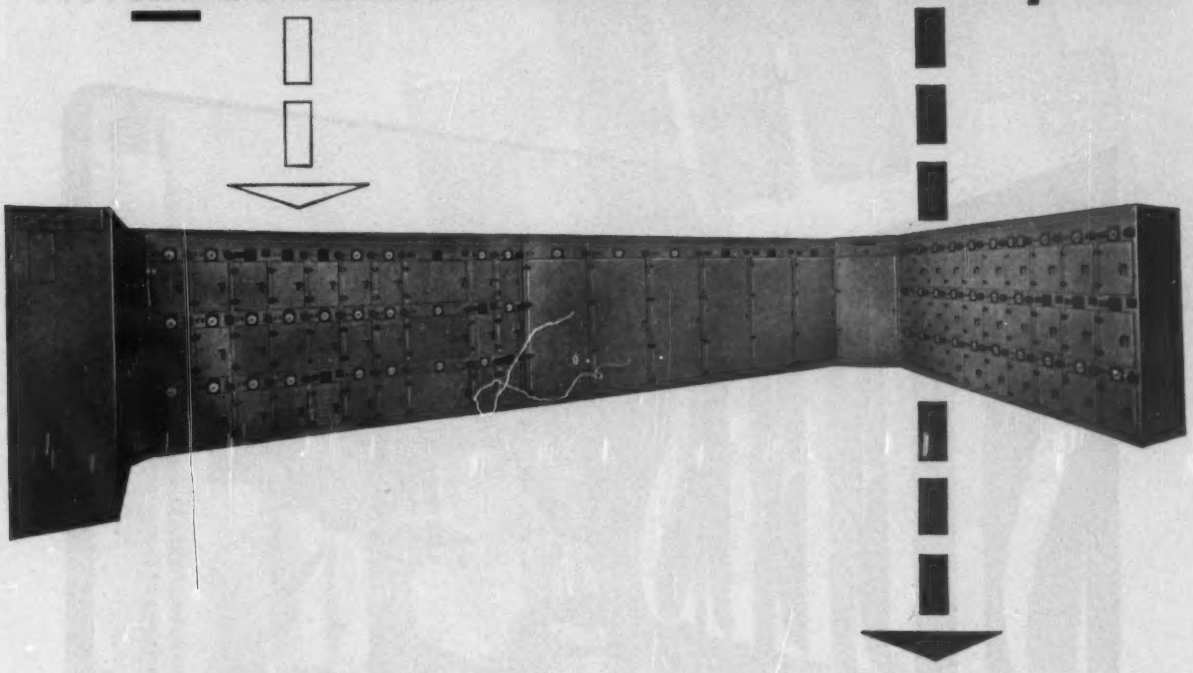
Reheating Furnaces
Lancashire Boilers
Tunnel Kilns
Water Tube Boilers
Heat Treatment Furnaces
Stress Relieving Furnaces
Glass Melting Furnaces
Aluminium Melting Furnaces

Honeywell

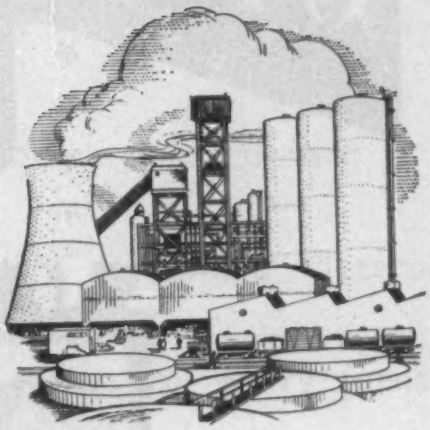
First in Control

75 motors in a large chemical plant

—all controlled from one central panel



This Dewhurst panel, recently installed in an extensive chemical plant situated on the North-East coast, provides positive central control of 75 motors, ranging from ½ to 50 h.p. located in various processing departments of the plant.



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INTERPRETING THE PRESENT AND PLANNING THE FUTURE!

FITNESS FOR PURPOSE STEELS

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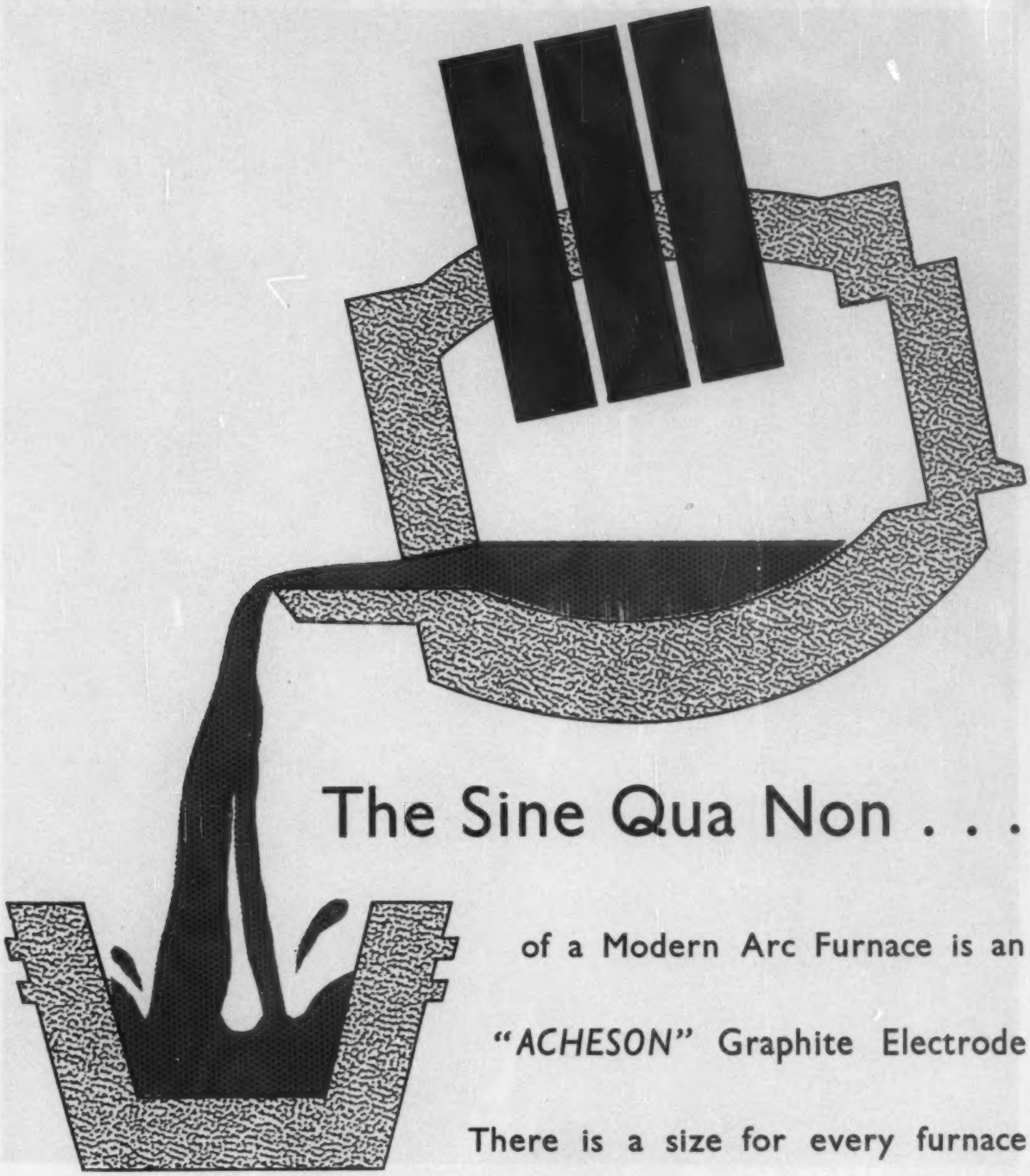

The Sine Qua Non . . .

of a Modern Arc Furnace is an

"ACHESON" Graphite Electrode

There is a size for every furnace

ACHESON TRADE MARK **GRAPHITE**

The term ACHESON is a registered trade mark

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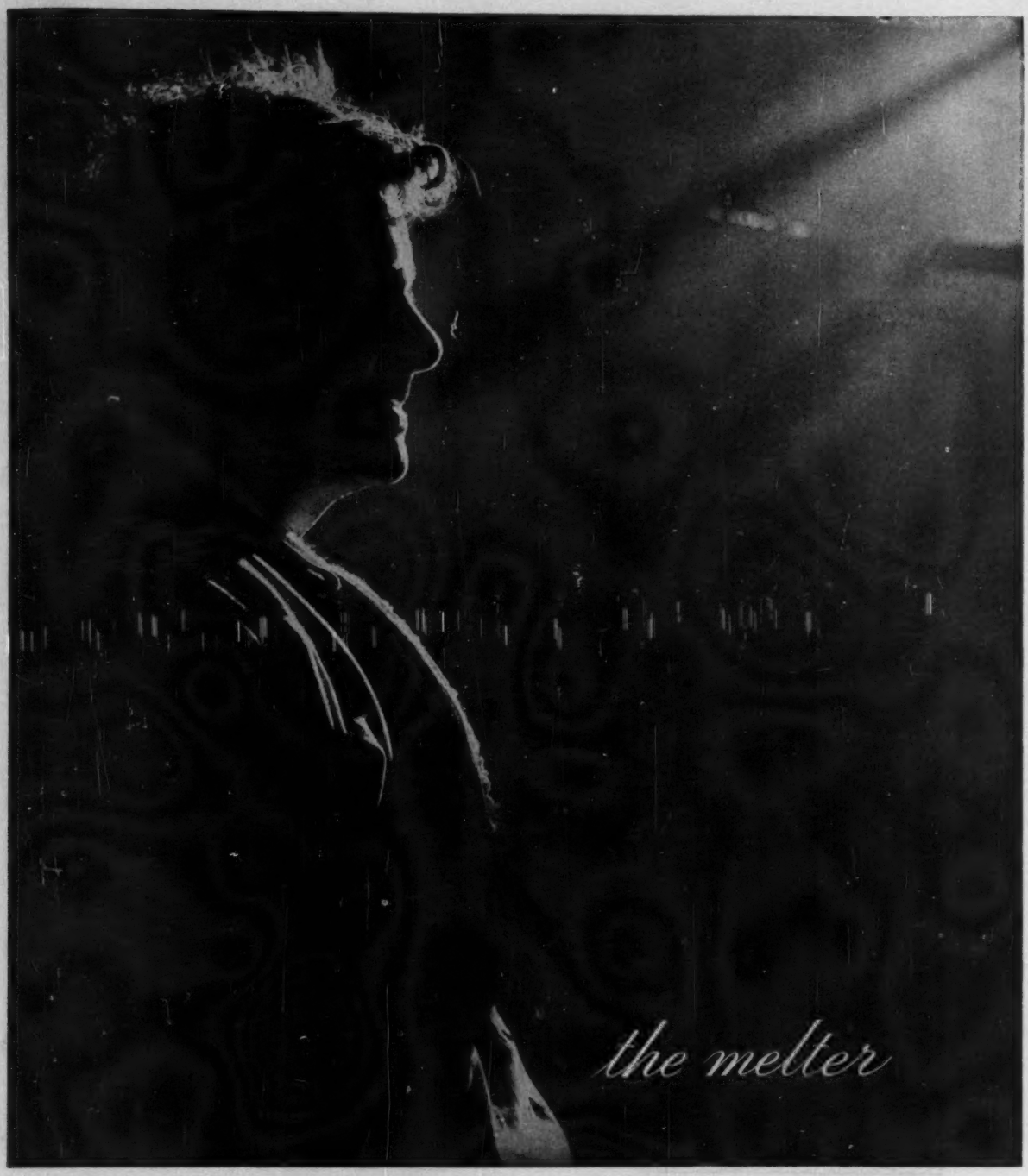

BROWN BAYLEY
STEELS LIMITED
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FOR *ECONOMY* IN FURNACE CONSTRUCTION

OUGHTIBRIDGE SERPEX 'A' BASIC BRICKS LAST LONGER

DOWNTAKES . . . "The advantages in the application to downtakes is the elimination of chrome oxide growth, with a life equivalent to those of chrome-magnesite bricks."

UPTAKES . . . "Similar results obtained in application to uptakes; in addition, in the target area, these bricks offer a strong resistance to abrasion by flame."

REGENERATORS . . . "Due to their basic properties and non-spalling characteristics, excellent results are reported in basic regenerator constructions, where high temperatures and resistance to the basic atmosphere, constitute a problem."

BACK WALLS . . . "A life equivalent to chrome-magnesite bricks is reported in many installations."

FRONT WALLS . . . "Very high mechanical strength and excellent bonding technique, in conjunction with steel sheet jointing, offer excellent resistance to damage by the charging machinery, and a life equal to that of chrome-magnesite bricks."

GAS PORT BARRELS . . . In this type of construction, Serpex 'A' Bricks reduce the problem of disintegration of the chrome, with the elimination of the chrome-oxide growth on the gas port sole. The high mechanical strength of these bricks gives a gas port lining equivalent to the campaign life of the furnace without repair."

RAMP ROOFS . . . "A Serpex 'A' ramp roof has given satisfactory service, completing the full campaign of the furnace. Trials made in checkers have also been successful."

These are some of the many favourable reports from users of Serpex 'A' basic bricks. It is evident from these that considerable saving without loss of performance can be enjoyed by using Serpex 'A' basic bricks in furnace construction.

Read these recommended applications

Specify The OUGHTIBRIDGE SERPEX 'A'

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SILICA FIREBRICK COMPANY LTD

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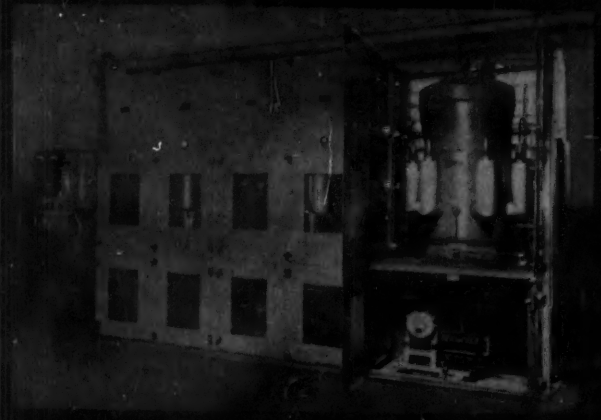
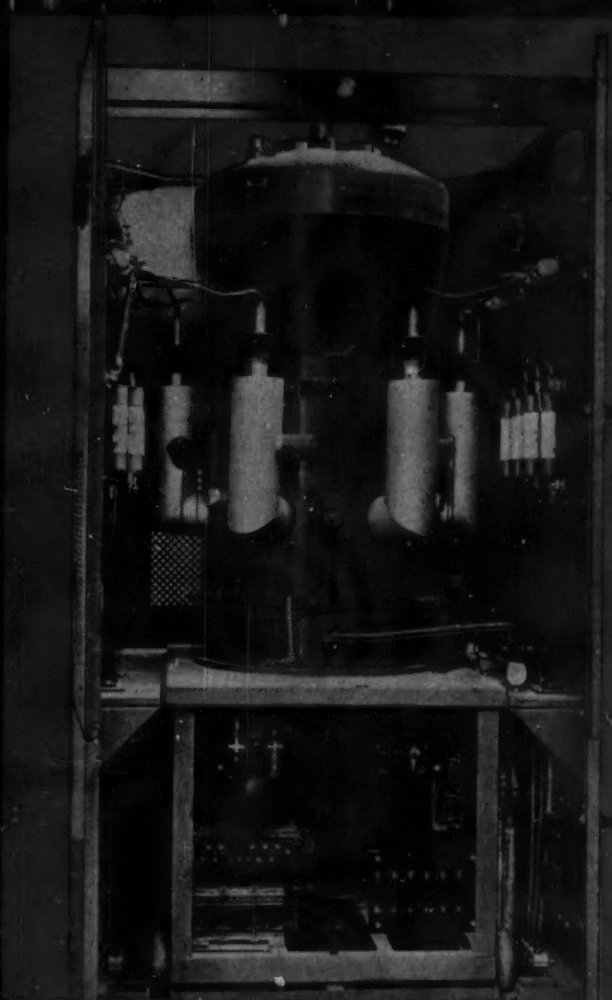


1000,

500 kW 600 volt rectifier equipment for electric locomotives at Port Kembla Australia for the Broken Hill Proprietary Steelworks

500 kW at 600 V rectifier in Western Australia. The first of its kind installed underground 800 ft. below ground

A 400 kW, 225V, G.E.C. grid-controlled pumpless air-cooled steel tank rectifier equipment undergoing "inclining test". This equipment formed part of a comprehensive contract for a large floating dock for the Admiralty, for which the G.E.C. acted as main machinery contractor. The rectifiers have to function perfectly under the conditions illustrated.



1224 kW mobile rectifier and substation specially designed for service with the Netherlands Railways

Single anode air-cooled steel tank, grid controlled rectifiers, controlling 220 kW driving equipment for high-speed printing press in Capetown

000 kW

pioneers and world leaders in this field

It was less than thirty years ago that G.E.C. pioneered the first water-cooled rectifier of wholly British design. Only five years later G.E.C. produced the world's first pumpless air-cooled steel tank unit.

Today over a million kilowatts of G.E.C. rectifiers are serving a diversity of industries all over the globe . . . operating under every climatic condition, from tropical heat and humidity to polar extremes of cold.

Some operate on a six month continuous full load duty cycle, others intermittently. But wherever they serve, they can be depended upon for that consistent reliability for which G.E.C. rectifiers are renowned.

G.E.C. mercury arc rectifiers

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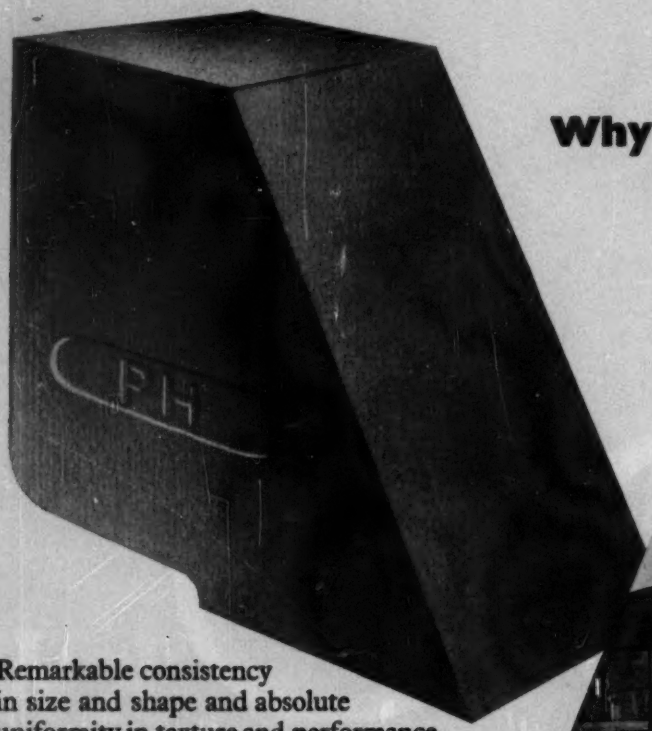
THE GENERAL ELECTRIC COMPANY LIMITED OF ENGLAND



Why are P.H. Silica Bricks in such demand?

Remarkable consistency in size and shape and absolute uniformity in texture and performance are the inherent features of Pickford Holland silica bricks. These exacting standards are maintained by the policy of installing the very latest plant and machinery, so that every process from quarry to finished brick, is regulated to the closest limits. Modern, fully instrumentated kilns (as illustrated) ensure even firing — an essential factor in the production of successful silica bricks. Up-to-date production methods in all departments are enabling Pickford Holland to keep pace with increasing demand for their refractories. More and more bricks for furnaces all over the world are being produced, and each and every brick conforms to the same high standards of manufacture.

A modern kiln at the Crook, Co. Durham works of Pickford Holland

PICKFORD HOLLAND *Silica Bricks*

CONSISTENT IN SIZE, SHAPE, TEXTURE AND PERFORMANCE

PICKFORD, HOLLAND & CO. LTD., 381 FULWOOD ROAD, SHEFFIELD 10. TEL. 33921

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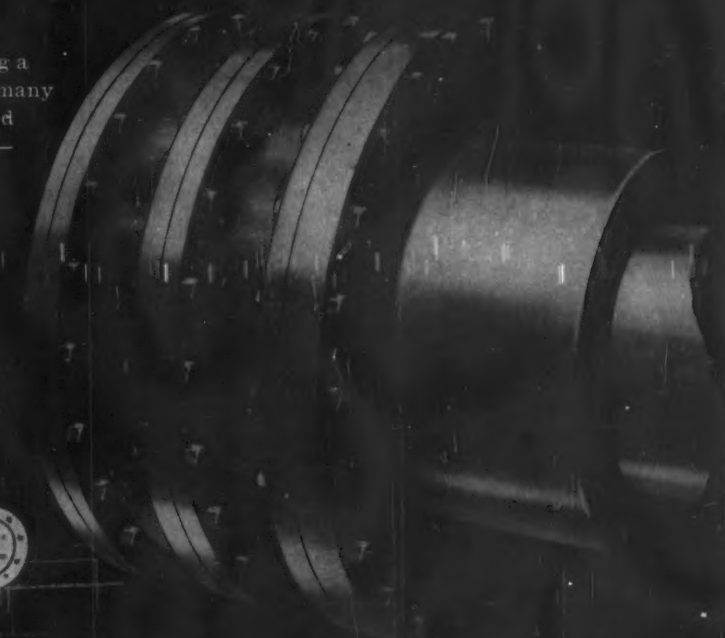
HOLSET FLEXIBLE COUPLINGS

Holset Flexible Couplings are giving a highly satisfactory performance in many leading steel works and are specified for their important characteristics :—

1. Ample torsional resilience.
2. Capacity to absorb shocks, torque fluctuations and accommodate substantial shaft misalignment.
3. Noiseless operation and absence of maintenance and lubrication.
4. Maximum protection to both prime mover and driven machine, hence lowest overall maintenance costs.



The Coupling illustrated transmits 21,000 H.P. at 40 r.p.m. to a Reversing Slabbing Mill.

Small coupling diameter means a low WR²—a very important factor in reversing mills—shafts up to 32" diameter can be accommodated.

There is a Holset design for every kind of drive and service

The HOLSET ENGINEERING CO. LTD. · TURNBRIDGE · HUDDERSFIELD

Telephone: Huddersfield 7480. Telegrams: Holset, Huddersfield.

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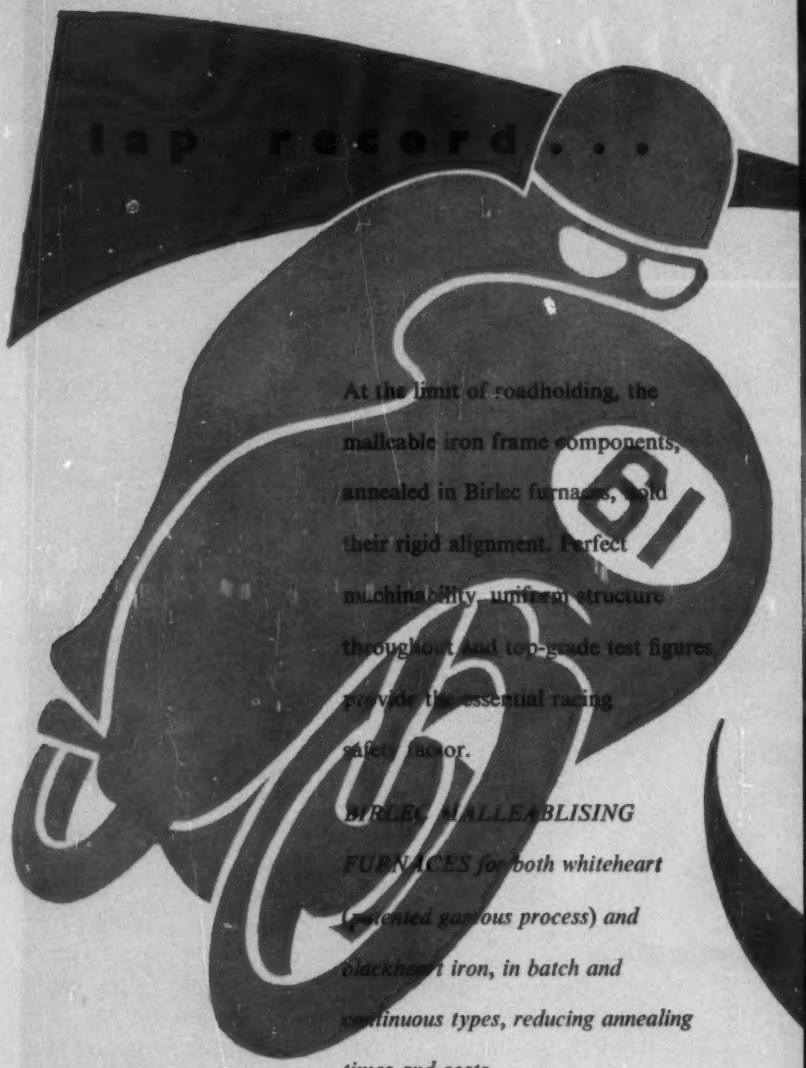

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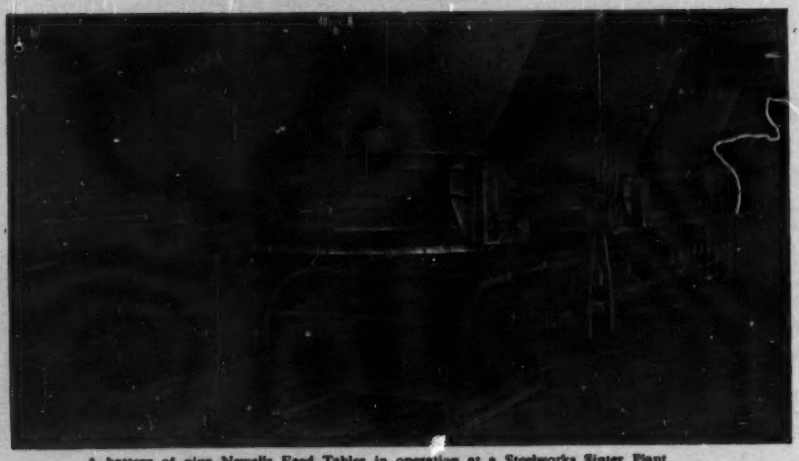

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Contents

THE IRON AND STEEL INSTITUTE

New Methods in Pig-iron Manufacture *by A. N. Pochwisnew* 337

An Experimental Investigation into Primitive Iron-smelting Technique *by E. J. Wynne and R. F. Tylecote* 339

Development of Methods for Isolating Structural Constituents in Steels *by W. Koch and H. Sundermann* 373

The Kinetics of Bainite Formation in a Plain Carbon Steel *by P. Vasudevan, L. W. Graham, and H. J. Axon* 386

Examination of an Early Bessemer Rail 391

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The Imatra Thermit Hot-topping Process *by A. I. Aitken, W. C. Fletcher, and G. Fenton* 349

A Review of Methods for Assessing Non-metallic Inclusions in Steel *by T. R. Allmand* 359

The Determination of Hydrogen in Steel by a Carrier-gas Technique *by C. E. A. Shanahan and F. Cooke* 381

A Survey of Forging Manipulators and their Applications *by P. L. Lillywhite* 394

POWDER METALLURGY JOINT GROUP

New Publication and Forthcoming Symposium 393

IRON AND STEEL ENGINEERS' GROUP

Vacuum-melting of Steels *by H. C. Child and G. T. Harris* 414

NEWS 432 **ABSTRACTS** 437

TRANSLATIONS 436

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JAMES THOMAS MILLS was born in 1916 and was educated at Bow Preparatory School, Durham, and at Oundle. He served a general engineering apprenticeship at the English Electric Company at Stafford, afterwards specializing in diesel-electric erection and testing.

From 1936 to 1938 he was the company's assistant district engineer in South Wales and South-west England, and towards the end of this period he was associated with the erection and commissioning of electrical drives and equipment for hot-finishing mills and for cold-mill process lines and auxiliaries.

Mr. Mills joined Richard Thomas and Co., Ltd., in 1939 as assistant electrical engineer in charge of blooming-mill and hot-strip mill electrical maintenance. Three years later he became responsible for the maintenance of all the electrical equipment at Ebbw Vale, and since 1954 he has been deputy chief electrical engineer at Ebbw Vale.

Mr. Mills is a member of the Ebbw Vale Metallurgical Society and was President of the Society for the year 1957-1958. In this capacity he served as an Honorary Member of the Council of The Iron and Steel Institute.

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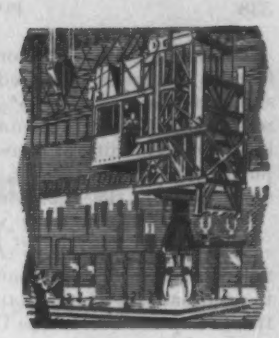

New Methods in Pig-iron Manufacture

By A. N. Pochwisnew

SYNOPSIS

This paper summarizes briefly some of the current trends in Soviet pig-iron production. These include blast enrichment by steam and oxygen, increased blast pressures, and the construction of larger blast-furnaces with extensive automation. It is considered that the blast-furnace will continue to be the most practical means of producing pig iron in the foreseeable future. 1626

IN THE U.S.S.R. 37·04 million tons* of pig iron (including 81% of iron for steel production) were produced in 1957. Various methods were adopted to increase the output capacity of the blast-furnaces. Steam enrichment of the blast is widespread. This permits blast-furnace operation with a blast of constant moisture content throughout the year. This constant moisture content is generally higher than the natural humidity of the blast in summer. The blast need not be cooled or dried, because in the U.S.S.R. the average moisture content does not exceed 2–3 vol-%, even in summer. A special feature of this steam enrichment of blast is the simultaneous increase of blast temperature, which according to theoretical calculations corresponds to 9° C/g of moisture per m³ of air blast.

More than 90% of the furnaces in the U.S.S.R. are operated on blast of constant moisture content and with simultaneous increase of blast temperature from 400–600° C to 850–1000° C. A further increase in blast temperature will come with the construction of new high-temperature hot-blast stoves, which have already been designed.

In connection with the control of moisture content of the blast, an investigation of the behaviour of hydrogen would be of great theoretical and practical interest. Work carried out in the U.S.S.R. showed that in blast with a moisture content of 25–30 g/m³, 40–70% of the hydrogen arising from the blast participates in the reduction of ore and escapes from the furnace as steam. This proportion increases with the moisture content of the blast. Thus there is an additional development of heat in the furnace in cases where the blast temperature is increased so that complete decomposition of the water vapour is achieved. The uniform operation of a furnace working with steam enrichment is apparently bound up with an extension of the oxidation zone, although this supposition cannot always be confirmed experimentally. With good ore preparation, which effects a uniform operation and permits a very high blast temperature, it is an advantage to maintain the moisture content within moderate limits; this content should not exceed the maximum natural humidity of the given locality.

The production of open-hearth pig-iron with low manganese content (0·3–0·8%Mn) as carried out in the eastern and southern areas of the U.S.S.R. also deserves mention. The sulphur content of this iron is kept within certain limits by the addition of dolomitic limestone or dolomite to the blast-furnace charge, even with the use of the high-sulphur coke from the south with 1·6–1·8%S.

The high-pressure process has spread considerably. Theoretical considerations supporting these methods and proposals for their practical application had already been made by the Russian engineer Asmansky and published in a Russian metallurgical periodical.† The possibility of considerably reducing the stack dust losses and of working the blast-furnace process more intensively was published by Korobov in 1942.(‡) Today 57 blast-furnaces are in operation with high-pressure processes in the U.S.S.R. and produce 80% of the total pig-iron production.

* 'Tons' are metric tons throughout this paper.

Manuscript received 18th August, 1958.

Professor Pochwisnew is with the Steel Institute, Moscow.

†P. M. Asmansky: *Zeitschrift der Russischen Metallurgischen Gesellschaft*, (XPMC) 1915, S.354.

‡I. Korobov: *Stal*, 1942, Nos. 10–12.

In comparison with normal operation the blast-furnace output is increased by 5–8%, the coke consumption decreased by 5%, and the stack dust loss reduced by 20–50%. Assuming a constant stack dust loss, the possibility of increasing the rate of throughput of a blast-furnace ($r\%$) is determined reasonably accurately by the equation

$$r\% = \left(\frac{P_2}{P_1}\right)^{0\cdot4} \times 100$$

where P_1 and P_2 represent the average gas pressure in accordance with the standard conditions for blast-furnace operation. In the U.S.S.R. five blast-furnaces work with a counter-pressure of 1·0–1·5 atm, the others with a pressure of 0·5–0·8 atm. The high-pressure process considerably reduces the costs of secondary gas cleaning because of an 80–90% reduction in the energy consumption. Very interesting results are obtained with a counter-pressure of 1·5 atm. In one plant which utilizes a burden of up to 100% self-fluxing sinter and works with a blast temperature of about 100° C and a counter-pressure of 1·5 atm, the ratio between the effective volume and pig iron is on average 0·64 m³/ton with a coke consumption of 0·64 m³/ton. The blast is not steam-enriched and contains 13–15 g/m³ of moisture. No scrap is added to the burden, and the CO_2 content of the gas reaches 17%. In comparison with this, with 1 atm counter-pressure and 800° C blast temperature the pig-iron production rose by 20% and the coke consumption fell by 10%.

Size of Furnaces and Constructional Features

The blast-furnaces built in the U.S.S.R. in 1938 were at that time, with 1300 m³ effective volume and 8 m hearth diameter, the largest in the world. Their technical success disproved the view of several Soviet and foreign metallurgists that large blast-furnaces would be uneconomical on account of the insufficient depth of the oxidation zone in the hearth at the height of the tuyeres.

The present-day maximum effective volume in various plants in the U.S.S.R. amounts to 1386 m³; furnaces with effective volumes of 1513 and 1719 m³ are being built and plans for a blast-furnace with an effective volume of 2286 m³ have just been completed. This has the following dimensions:

(i) Hearth dia. 10·3 m
(ii) Upper bosh line dia. 11·5 m
(iii) Shaft dia. 7·7 m.

Of these blast furnaces, 40% are welded, 20 units have a hearth of carbon blocks. Most of the furnaces are equipped with automatic controls for elevating the charging buckets, charging apparatus with rotating distributors, counter pressure, blast-preheating and steam enrichment, utilization of the exit gas in the hot-blast stoves, etc. In two works the burden-charging cars are automatically controlled. A comprehensive scheme of automation for blast-furnace operation is being developed.

As a result of the steps taken to improve the production of pig iron, average coke consumption throughout the country was reduced to 817 kg/ton and amounts in some works to only 630–650 kg/ton of pig iron. Throughput of these blast furnaces is high. During 1957 the ratio of effective volume (m³) to the day's production (tons) amounted on the average to 0·79; in some of the larger works it was 0·58–0·59 for individual furnaces. Abroad, this ratio is usually less favourable and the working of the furnace is not so intensive. For example, a ratio of 0·58 was achieved in Sweden in a 250-m³ furnace which worked with a 100% self-fluxing sinter charge with a coke consumption of 615 kg/ton. There are several very promising possibilities for the further improvement of the blast-furnace process.

Oxygen Enrichment of Blast

It is believed that the U.S.S.R. was the first country to apply oxygen enrichment of the blast on an industrial basis in a works, from 1939 to 1941. This furnace produced chiefly ferrosilicon with a silicon content up to 17–18% and the operating results were very good. After the war two blast-furnaces worked continuously with oxygen-enriched blast. One of these, with an effective volume of 330 m³, produces ferromanganese; the other (effective volume 930 m³) produces cast iron. Today three further works operate with enriched blast. The injection of a relatively small volume of oxygen into the blast brings about an increase in production. In the production of ferrous alloys the performance of furnaces which utilize a blast containing an oxygen content of 32–35% can be increased in proportion to the increase in the percentage of oxygen, and even further. The increase depends on the high gas permeability of the column of the burden which to a large extent consists of coke. A certain reduction of the coke consumption is likewise possible. In the production of pig iron and iron for steelmaking, with a constant gas volume per unit time, the increase in productivity can be calculated from the equation:

$$r\% = \frac{W_2 - W_1}{W_2(100 + W_1)} \times 10^4$$

where W_1 is the initial oxygen percentage including the oxygen of the moisture in the blast and W_2 the oxygen percentage after enrichment of the blast. The volume of the enriched blast necessary in this case amounts to the following as a percentage of its original volume:

$$W = \frac{W_1 \times 10^4}{W_2(100 + W_1)}$$

A marked reduction of the coke consumption in the production of foundry pig iron and iron for steelmaking is not to be expected and oxygen content in the blast cannot be appreciably increased without disturbing the uniform descent of the charge in the furnace. Oxygen injection into the suction box of the blower is preferable.

The foregoing data are very far from complete, but they show that the blast-furnace engineers in the U.S.S.R. are continually striving to improve operating results. The prospects of development in the field of pig-iron production lead one to expect that in spite of the introduction of new methods, and further development of those already in use, the blast-furnace process will hold its own for a long time to come. It will remain the fundamental method for the production of iron from ore and will continue to determine the structure of iron and steelworks.

An Experimental Investigation into Primitive Iron-smelting Technique

By E. J. Wynne and R. F. Tylecote

SYNOPSIS

A simple hearth furnace has been constructed and the production of iron by the primitive method has been attempted. Several methods of charging the ore have been employed and the effects of varying air flow, tuyere size, and ore and charcoal sizes have been investigated.

Prepacking the ore in the hearth and correctly crushing the charcoal gave the best iron yield. The desirability of adequate top insulation to the furnace has been discussed. 1505

INTRODUCTION

SOME SIX THOUSAND YEARS ago, man learned to extract metals from their ores. Archaeologists consider that non-ferrous metals, such as copper and tin, were the first to be smelted. Two thousand years of development in metallurgical technique were needed before iron came to be commonly used. Excavations have brought to light many primitive iron-smelting hearths; near outcrops of ironstone or deposits of bog iron ore, the ploughing of a single field may unearth a score of such hearths. These are hemispherical holes in the ground, 1–6 ft in diameter, and many contain charcoal and also the waste products of the smelting process, in the form of slags and cinders, both rich in iron oxides. In other places, large heaps of cinders and slag are found.

The fuel appears to have been mainly charcoal, the combustion products forming the reducing agent. The exact conditions necessary for the successful production of iron (in the more primitive types of hearth) are unknown. The waste products indicate that temperatures of the order of 1100°C were attained, but the air flow required to give such a temperature and the general method of smelting are mainly matter for se culation.

The following experiments were designed to investigate the variables of the process and their effect on the production of iron, and to correlate archaeological findings with present metallurgical knowledge.

REVIEW OF PREVIOUS INFORMATION

Since extremely comprehensive accounts of early iron-smelting techniques have recently been written by Coghlan[1] and Schubert[2] it is intended to confine this review to papers which are particularly pertinent to the experimental work which follows.

Early smelting furnaces were shallow bowl-shaped pits, perhaps lined with clay. The oldest iron-smelting hearth discovered in the British Isles was at Kestor (Devon)[3] in an Iron Age settlement founded after 400 B.C. The hearth was a small, roughly circular, clay-lined pit, 15 in. at its longest, 10 in. at its widest, and only 6 in. deep. There was a large mass of iron cinder adhering to one side, the analysis of which is given in Table I. The earliest hearths were all 12–18 in. in diameter.[4] O'Kelly has described the remains of smelting operations found at a site in Ballyvourney (Co. Cork),[5] and from an examination of the slags found has deduced that the hearth used was only 7 in. in diameter. This estimate would appear to be very much on the small size and it is considered that the assumption made in the estimation of hearth size is incorrect.

Excavations at Great Casterton (Rutland) in 1956 under the direction of Dr. P. Corder[6] brought to light part of a Roman bowl furnace, shown diagrammatically in Fig. 1. The ore found prepacked in the furnace was a local high-grade ore, containing 80% Fe_2O_3. The slag, also found *in situ* (probably the remains of a previous smelt), had the composition shown in Table I. On an earlier occasion,[7] pieces of cinder were found on this site, and their analysis is also included in Table I.

Cinders and large quantities of slag are found at most smelting sites. Both are very similar in chemical composition and are waste products of the direct method of smelting, having compositions of 60–70% iron oxides, and 20% SiO_2, the actual figures depending on the ore used. A comprehensive description has been given by Straker.[8] Although similar in chemical composition, their physical appearances differ greatly and it is by this means that they are distinguished. Cinders, as their name suggests, are very porous and the shape of individual ore lumps can still be distinguished. Although some low-melting-point constituent has bonded the whole together, the remains of pieces of charcoal, or wood, can be seen embedded in the cinder. Part of a cinder found at Great Weldon (Northants) which weighed 80 lb, is shown in Fig. 2, in which the structure of wood and charcoal can be seen. It is believed that cinders are partially smelted ores which have been in such a position in the furnace that reduction has been unable to proceed to completion.

The slags found are usually black in colour, indicative of high iron-oxide content. They have smooth, rounded surfaces and are much denser than cinders (Fig. 3), having been formed by the fluxing of gangue materials with iron oxide to give a fluid slag. Slags are much more common than cinders, possibly because the latter could be broken up, and were sufficiently porous to be resmelted. The formation of slags in the primitive smelting hearth has been ably discussed by Neumann.[9]

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The authors are with the Department of Metallurgy, University of Durham, King's College, Newcastle-on-Tyne.

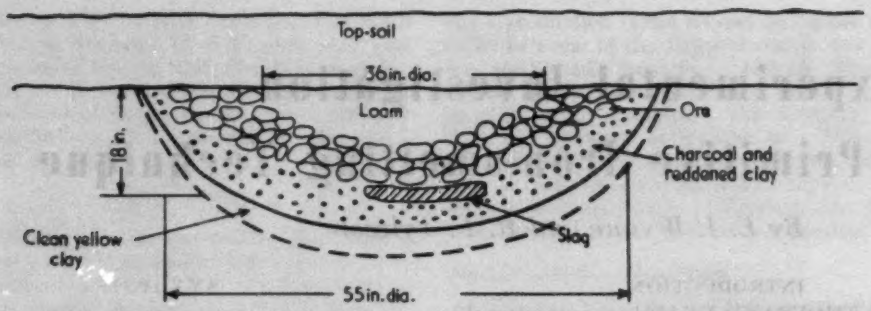


Fig. 1—Remains of iron-smelting hearth found at Great Casterton (Rutland)

Thus, archaeological excavations can give much information on the type of smelting hearth used, and on the products of smelting, both useful and waste, but they tell nothing of the actual operation of the furnace. Information on this latter subject comes from several sources. The principal source is in the descriptions given by travellers who have seen primitive smelting furnaces in operation. The usual method[10–13] consisted of heaping either alternate layers of ore and charcoal, or a mixture of ore and charcoal, into the hearth, inserting the bellows over the lip of the hearth, and urging combustion to the utmost power of the bellows for several hours. The alternative [14, 15] was to prepack the ore in the hearth so that charcoal was present between the ore and the tuyere. As combustion proceeded more charcoal was added. In each case the result was sponge iron containing quantities of slag. This was reheated and forged to compact the iron and expel the slag.

Books by such men as Agricola[16] and Biringuccio,[17] contemporaries of the medieval smiths, give a good qualitative picture of the methods of smelting iron, but they lack quantitative facts.

The mechanism of the formation of iron in primitive hearths has been discussed by Neumann.[18] In his opinion, as the ore in the charge is heated, a slag forms by the fluxing of silica with the oxides of iron. The oxides of iron, which may be magnetite or wüstite, are then reduced by particles of solid carbon, either from the charcoal or from the breakdown of carbon monoxide to carbon dioxide and carbon. The iron, which is formed at a temperature below its melting point, is not liquid when it separates but in the form of tiny crystals. The tiny particles grow and gradually build up a sponge, which still contains entrapped slag. This iron sponge, or bloom, is withdrawn and forged.

O'Kelly has experimented with a reconstruction of the Kestor furnace[3] and claims to have had considerable success in producing iron, but no details have yet been published.

Table I

COMPARISON OF ANALYSES OF VARIOUS CINDERS AND SLAGS

	Kestor Cinder	Great Casterton Slag	Great Casterton Cinder
Fe_2O_3	17·4%	11·9%	7·7%
FeO	48·3%	61·8%	64·4%
SiO_2	21·4%	20·9%	18·2%
Al_2O_3	7·3%	1·9%	3·7%
CaO	0·4%	2·4%	1·8%
MgO	0·1%	0·9%	0·1%
TiO_2	0·3%	n.d.	n.d.
MnO_2	n.d.	nil	1·4%
	95·3%	99·8%	97·3%

n.d. = not determined

EXPERIMENTAL PROCEDURE

Furnace Construction

Descriptions of early smelting furnaces show them to be merely holes in the ground, perhaps lined with clay, and so the hearth constructed was an attempt to simulate the conditions of such a furnace. An open-topped box of insulating firebricks was built, inside which the hearth was formed by ramming moist ganister round a pattern 9 in. in diameter and 7 in. deep. Sheathed chromel/alumel thermocouples were

Fig. 2—Part of cinder from Great Weldon (Northants)

Fig. 3—Section of piece of slag from Weardale

inserted through the walls of the hearth to measure the temperature at different levels in the hearth.

Provision was made for the insertion of one or two tuyeres, for which silica tubing was used. To the end of one of the tuyeres a T-piece of brass was rigidly attached, air entering the tuyere through the limb of the T-piece. Over the other end of the cross-piece a circle of glass was attached, enabling observations to be made of the centre of the hearth while the furnace was in operation. Details of the hearth are shown in Fig. 4. Air was supplied from an electrically driven compressor and was measured by means of flow meters.

Finally, a piece of steel pipe, 12 in. high and 10 in. in bore, was placed over the hearth to form a reservoir for the burden.

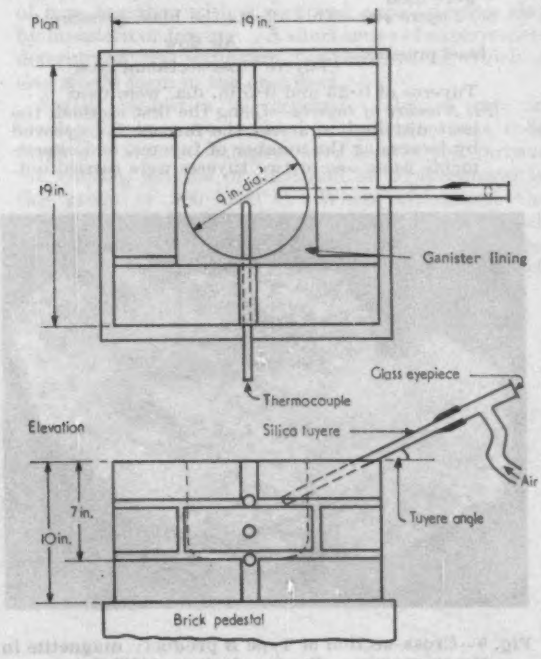


Fig. 4—Details of construction of experimental hearth

Materials Used

The fuel was lump charcoal, made from beech wood. Two types of iron ore were used, a rich, fairly refractory Newfoundland ore and a self-fluxing Northants ore. This latter ore was from an outcrop, close to the Roman villa at Great Weldon where the cinder shown in Fig. 2 had been found. Before smelting, all ores were calcined for some hours at 800° C in an oxidizing atmosphere.

Furnace Operation

It was realized that there were two distinct methods of operating the furnace.

Method I—Ore and Charcoal Mixture Charged into Stack

This is the method described in the majority of papers relating to the subject and so seemed likely to be the most successful The hearth and stack were first filled with charcoal, which was then ignited. As combustion proceeded, the reservoir was topped up with alternate layers of ore and charcoal until the desired amount of ore had been added. The usual amount of ore in each layer was $\frac{1}{2}$ lb. Depending on air flow, 4–5 h were required for a layer of ore to pass down into the hearth, during which time it was subjected to the reducing action of carbon monoxide. When all the reduction products had collected in the hearth, charcoal was added for some further time to

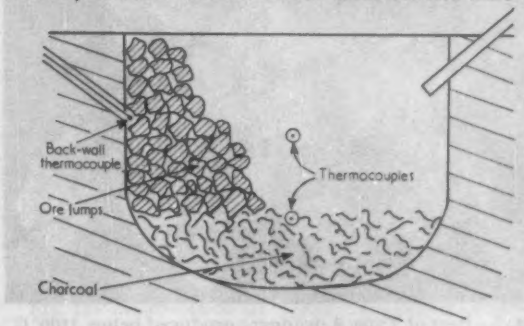


Fig. 5—Method of packing ore in hearth

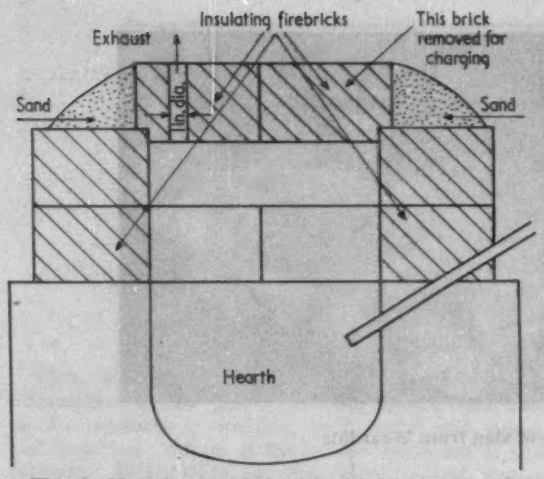


Fig. 6—Hearth provided with insulated 'dome'

permit the separation of slag and metal to proceed. After cooling for some hours the bloom was withdrawn and examined.

It was desired to know how far down the furnace the ore lumps moved before reduction was complete. By attaching pieces of ore to the ends of nickel wires it was possible to withdraw them for microscopic examination.

Method II—Prepacking of Ore in Hearth

This method entailed packing all the ore in the furnace before charging charcoal. The ore was packed against the wall opposite the single tuyere used, in such a way that, although removed from the combustion zone, it was subjected to the reducing action of the carbon monoxide. The bottom thermocouple was removed and placed in the wall behind the ore. The method of packing the ore is shown diagrammatically in Fig. 5. It appears to have been the practice in many primitive hearths to build a dome of thick clay over the charge, serving both as a reservoir for fuel and as a means of conserving heat. For this reason the steel pipe was later replaced by a square brick construction, 6 in. high with walls $4\frac{1}{2}$ in. thick. To encourage the flow of carbon monoxide through the ore, the exhaust gases escaped through a hole directly above the ore. Details are shown in Fig. 6.

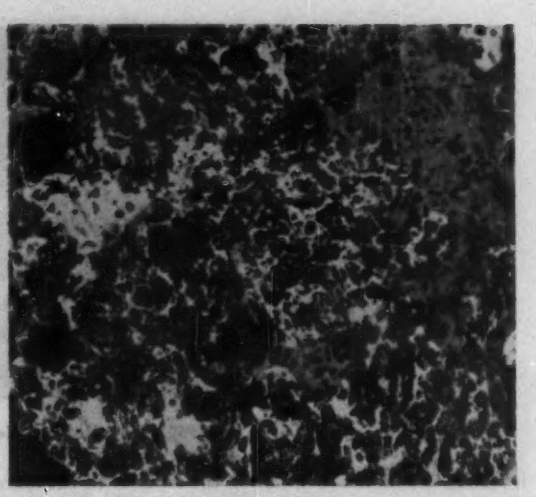


Fig. 8—Microstructure of Type *A* product; wüstite grains in glassy matrix × 300

Variables of Process Investigated

It was extremely difficult to achieve standardization of method, so many variables being inherent in the process. The factors investigated included:

(i) *Air flow*—This governs the temperature existing in the hearth. Rates of flow of 1·5–3·2 ft³/min were used

(ii) *Tuyere size*—This affects the blast pressure:

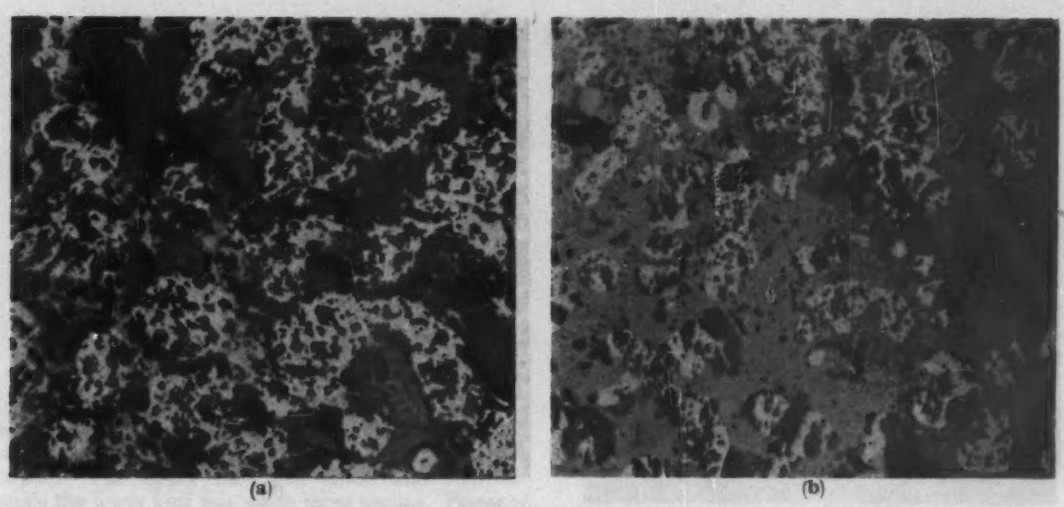
$$\text{blast pressure} \propto \frac{\text{Air flow}}{\text{Tuyere cross-sectional area}}$$

Tuyeres of 0·25 and 0·5 in. dia. were used

(iii) *Number of tuyeres*—Using the first method, the heat distribution across the furnace is improved by increasing the number of tuyeres, and experiments using one or two tuyeres were carried out.

Fig. 7—Part of Type *A* product; produced below 1100° C from Newfoundland ore

Fig. 9—Cross-section of Type *B* product; magnetite in glassy matrix. Produced above 1100° C (approx. full size)



(a) (b)

Fig. 10—Microstructure of Type *B* product showing (*a*) upper part, wüstite grains and some glassy slag; (*b*) lower part, glassy slag containing wüstite grains × 250

When the ore was prepacked in the furnace only one tuyere was used

(iv) *Tuyere angles* of 20–60° were used

(v) *Ore size*—The effect of sizes up to 2 in. was investigated and also the effect of the addition of fines to the burden

(vi) *Charcoal lump size.*

Slagging Properties of Ores

One of the aims of this work was to produce iron blooms which could be forged. To be capable of this the iron must be compact and, at the relatively low temperatures attained, the only method of achieving this property seems to be one of cementing the grains of iron together with a slag and expelling this slag by liquation or forging. A short series of experiments determined the minimum temperature at which a slag would form in the ores used.

Small quantities of crushed, calcined ore, in fireclay boats, were reduced in hydrogen in a tube furnace. The ore samples were left in the furnace for varying lengths of time and at temperatures in the range of 900–1200° C. When withdrawn the reduced ore samples were examined. Those which were friable would have been impossible to forge, whereas those which were hard and dense and which showed a glassy slag were thought to be suitable for forging.

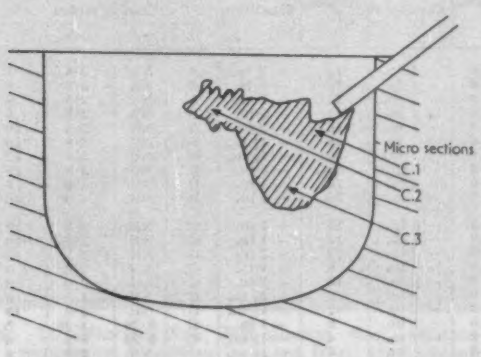


Fig. 11—Position of Type *C* product

EXPERIMENTAL RESULTS

Products of Smelting

The smelting experiments gave rise to four general types of product. These have been arbitrarily classified as types *A*, *B*, *C*, and *D*. The products of each type differed slightly amongst themselves, but the general shape and structure, both micro and macro, were essentially the same. A description of each type is given, followed by a table giving details of the variables investigated and their effect on the type of product.

The mixed-charge technique gave rise to three types of product *A*, *B*, and *C*.

Type A was formed when two tuyeres were used and when the maximum hearth temperature was

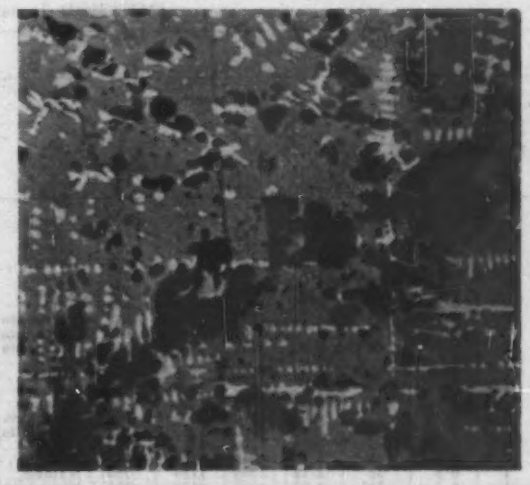
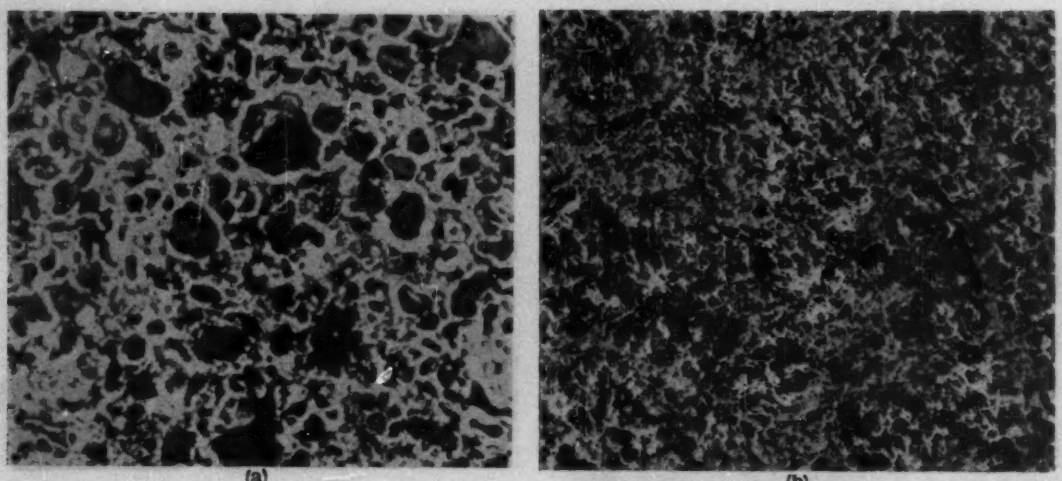


Fig. 12—Microsection C3. Slag of magnetite dendrites in glassy matrix × 150



(a) (b)

Fig. 13—Microsection *C2*: (*a*) iron network and entrapped slag; (*b*) wüstite and glassy slag

below 1100° C. Figure 7 is a photograph of part of the product which was found centrally situated in the hearth, below the level of the tuyeres. Individual ore lumps are still visible, having been only slightly sintered together at their edges, the whole being homogeneous, very porous, and friable. This suggests that the temperature had been insufficient to form a free-running slag capable of cementing the whole together. The substance was non-magnetic and microsections from various parts showed a random distribution of white wüstite and darker slag, probably of the fayalite type (Fig. 8).

Type B was also formed when two tuyeres were used, but when the maximum temperature was higher than 1100° C. The product, a cross-section of which is shown in Fig. 9, was found centrally situated in the hearth and was extremely dense, suggesting that the temperature had been sufficiently high to fuse at least one consitutent. Most of the products of this type were non-magnetic (wüstite), but a few which were magnetic were found to contain magnetite.

A comparison of the structure at the top (Fig. 10*a*) and bottom (Figure 10*b*) of the mass shows quite clearly that separation has occurred to a considerable extent, a glassy slag liquating to the bottom, leaving a high concentration of iron oxides near the top. In the figures shown, the iron oxides are wüstite, but the degree of oxidation, i.e. wüstite or magnetite, depended upon conditions such as air flow and temperature.

Type C was the product formed using only one tuyere and a mixed charge. Its shape and position

Table II

EFFECT OF VARIABLES ON IRON YIELD WHEN CHARGING ORE–CHARCOAL MIXTURE (METHOD I, using Steel Reservoir)

Conditions							Charge					Product			Time, h
Tuyeres			Air flow, ft³/min	Temperature, °C			Ore			Charcoal		Type	Weight, lb		
Number	Diameter, in.	Angle		I Top	II Centre	III Bottom	Type	Weight, lb	Condition	Weight, lb	Condition		Iron	Oxides	
2	0·25	30°	1·60	800	950	500	N'fland	3·0	– 1 in.	12	– 2 in.	A	Nil	2·5	7
2	0·25	30°	1·75	900	1050	600	N'fland	3·0	– 1 in.	12	– 2 in.	A	Nil	2·5	7
2	0·25	30°	2·13	1000	1100	700	N'fland	3·0	– 1 in.	12	– 2 in.	A	Nil	2·5	8
2	0·25	30°	2·83	1100	1250	750	N'fland	3·0	– 1 in.	15	– 2 in.	B	Nil	2·5	8
2	0·25	30°	3·18	1100	1280	750	N'fland	4·0	– 1 in.	16	– 2 in.	B	Nil	3·5	10
2	0·25	45°	2·50	1000	1200	750	N'fland	4·0	½–1 in.	16	– 1½ in.	B	Nil	3·8	10
2	0·25	45°	3·18	1100	1300	800	N'fland	4·0	½–1 in.	16	– 1½ in.	B	Nil	3·8	12
2	0·25	45°	3·18	1100	1300	850	Northants	4·0	– ½ in.	16	– 1 in.	B	Nil	3·8	10
2	0·5	30°	3·18	1100	1200	800	Northants	4·0	– ½ in.	16	– 1 in.	B	Nil	4·0	8
2	0·5	45°	3·18	1100	1300	800	Northants	4·0	– ½ in.	20	– 1 in.	B	Nil	4·0	10
1	0·25	10°	2·83	1300	700	300	N'fland	3·0	– ½ in.	12	– 1 in.	C	Nil	2·8	10
1	0·25	30°	2·83	1250	900	450	N'fland	3·0	– ½ in.	12	– 1 in.	C	Nil	2·8	10
1	0·25	30°	2·50	1200	1000	400	N'fland	3·0	– ½ in.	12	– 2 in.	C	Nil	2·5	10
1	0·25	45°	2·83	1200	1250	1000	Northants	2·0	– ½ in.	9	– 1 in.	C	Nil	2·0	8
1	0·25	45°	2·83	1200	1250	950	Northants	2·0	– ½ in.	10	– 1 in.	C	Nil	2·0	8
1	0·5	45°	2·83	1200	1250	750	N'fland	2·0	– ½ in.	6	– 1½ in.	C	Nil	1·8	8
1	0·5	45°	3·18	1250	1300	750	N'fland	3·0	– ½ in.	9	– 1½ in.	C	Nil	3·0	10
1	0·5	30°	3·18	1300	1150	750	N'fland	2·0	– 1 in.	6	– 1 in.	C	0·25	1·25	5
1	0·5	30°	2·83	1250	1100	700	Northants	1·0	– 1 in.	4	– 1½ in.	C	0·25	0·5	4
1	0·5	30°	2·83	1250	1100	700	Northants	1·0	– ½ in.	8	– 1½ in.	C	Nil	0·9	8

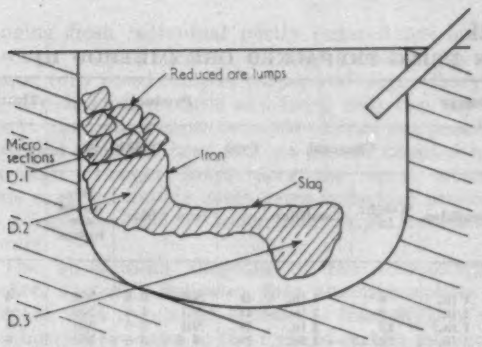


Fig. 14—Result of using prepacking technique

in the hearth are shown in Fig. 11. In all cases the bloom was in close proximity to the tuyere, and occupied only half the furnace, that nearest to the tuyere. The upper half was dense and compact while the lower half was much more porous. Pieces of charcoal were entrapped in the lower parts and many long black drops of slag extended downwards through the charcoal. The lower half (*C*3) consisted of a glassy slag of the fayalite type with well marked dendrites of magnetite (Fig. 12).

The upper half, especially that farthest removed from the tuyere (*C*2), was often strongly magnetic, iron being present under certain conditions. Figure 13*a* shows the structure of iron in a continuous network, trapping small amounts of slag in pockets. In most cases the main constituent was wüstite (Fig. 13*b*). The region nearest the tuyere always consisted of wüstite (Fig. 10*a*) or magnetite and some glassy slag. Table II shows the results of all heats using the mixed-charge technique.

Experiments on the reduction of ore lumps during their passage through the hearth showed conclusively that, under the conditions investigated, complete reduction to iron was achieved some distance above the tuyere.

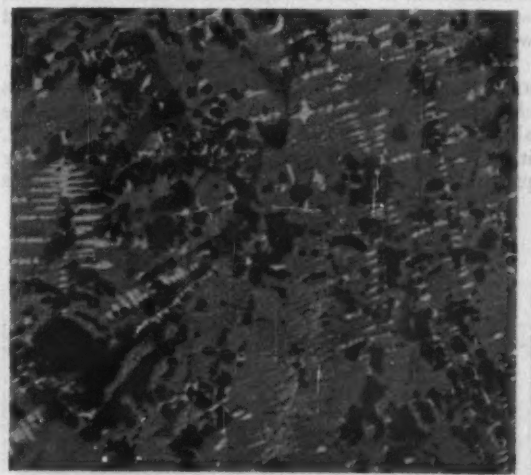


Fig. 15—Microsection *D*3: glassy slag containing magnetite dendrites liquated from iron shown in Fig. 17 × 300

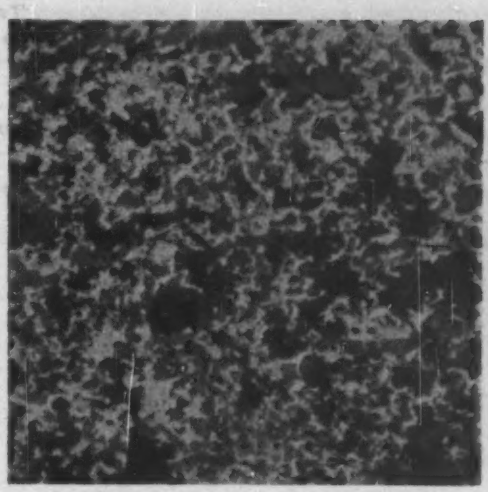


Fig. 16—Microsection *D*1: porous iron and slag × 300

The method of prepacking the ore in the hearth gave rise to a further product, *Type D*, which could be divided into three distinct regions as shown diagrammatically in Fig. 14. Across the bottom of the hearth (*D*3) was spread a thin layer of slag of the fayalite type with primary dendrites of magnetite (Fig. 15). The slag had been fluid, and where the hearth was hottest most slag had collected. The second part of the product (*D*2) consisted of a piece of iron, dense and hard, and on top of this there were pieces of reduced ore (*D*1). These still maintained the shape of the ore lumps charged but were soft and friable. They were very porous and consisted of an intimate mixture of iron grains and slag (Fig. 16). There appears to have been no agglomeration of iron particles, whereas in the compacted iron (Fig. 17) the iron has agglomerated into larger particles surrounded by thin layers of slag.

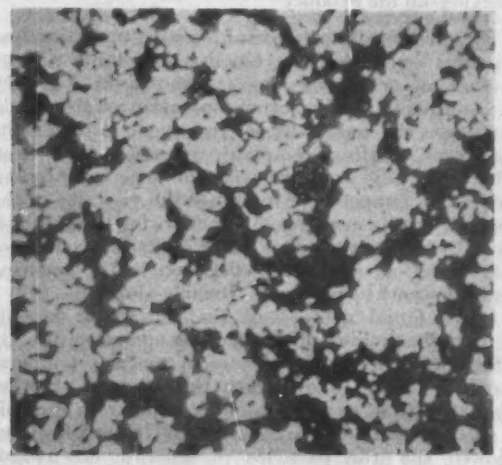


Fig. 17—Microsection *D*2: agglomerated iron particles (white), grey areas slag, dark areas mountant × 300

Table III
EFFECT OF VARIABLES ON IRON YIELD WHEN USING PREPACKED ORE (METHOD II)

Conditions						Charge					Product				Time, h
Tuyere		Air Flow, ft³/min	Temperature, °C			Ore			Charcoal		Type	Weight, lb			
Diameter, in.	Angle		I Top	II Centre	IV Back	Type	Weight, lb	Condition	Weight, lb	Condition		Iron	Slag	Reduced ore lumps	
(a) *Using Reservoir*															
0·25	30°	2·83	1250	900	500	Northants	1	— 1 in.	6	— 1 in.	D	Nil	0·8	Nil	4
0·25	30°	2·83	1250	1050	600	Northants	2	— 1 in.	8	— 1 in.	D	Nil	1·8	Nil	4
0·25	45°	2·83	1250	1100	800	Northants	3	— 1 in.	12	— 1 in.	D	Nil	2·5	Nil	6
0·25	45°	3·18	1300	1150	850	Northants	4	— 1 in.	12	— 1 in.	D	0·3	3·5	Nil	8
0·25	45°	2·83	1250	1050	600	Northants	6	— ½ in.	18	— 1 in.	D	0·5	4·0	0·5	9
0·25	60°	3·00	1050	1150	700	Northants	4	— ½ in.	16	— 1 in.	D	0·3	3·5	Nil	6
0·5	45°	2·83	1250	1150	800	Northants	4	— ½ in.	16	— ½ in.	D	0·3	1·3	1·5	6
0·5	45°	2·83	1250	1150	800	N'fland	4	— ½ in.	16	— ½ in.	D	0·5	1·0	1·5	6
0·5	45°	2·83	1250	1150	750	Northants	4	— ½ in.	16	— ½ in.	D	0·8	0·9	1·5	6
0·5	45°	2·83	1250	1150	750	N'fland	4	— ½ in.	16	— ½ in.	D	0·8	0·9	1·0	6
(b) *Using Insulated Dome*															
0·5	45°	3·18	1350	1200	850	Northants	4	— ½ in.	12	— ½ in.	D	0·3	3·5	Nil	6
0·5	45°	2·83	1350	1150	800	Northants	4	— ½ in.	12	— ½ in.	D	0·5	3·0	Nil	6
0·5	45°	2·50	1250	1150	800	Northants	4	— ½ in.	12	— ½ in.	D	0·8	2·8	Nil	6

A typical slag (*D*3) formed in this process from Northants ore had the following analysis:

FeO	Fe_2O_3	SiO_2	CaO	MgO	Al_2O_3	TiO_2
40·4%	23·7%	16·1%	5·3%	4·6%	7·7%	0·5%

Results of this technique are given in Table III.

Slagging Properties of Reduced Ores

Table IV shows the results of the experiments carried out to determine the minimum temperature at which a slag would form in the ores investigated. Powdered samples of ore were heated under reducing conditions and the products after cooling were tested for malleability.

These results show that malleability was only present when a fluid slag had formed, the slagging temperature of the Northants ore being about 50° C below that from Newfoundland. No liquation had occurred.

Working-up the Product

The product of a successful smelting operation was a porous iron lump or 'bloom,' containing a large amount of entrapped slag (as shown in Fig. 17). It is probable that a better separation of slag could have been effected by longer treatment in the smelting furnace after complete reduction had been achieved. This would probably have necessitated an increase in temperature to reduce the viscosity of the slag. There is evidence,[19] however, for the use of a second hearth, sometimes call a 'stryng-hearth,' for this operation, since the separation in the smelting furnace seems to proceed extremely slowly.

It was found in this work that it was not possible to forge the product of the smelting operation directly after removal from the furnace at smelting temperature. In order to overcome this problem, further separation was carried out in a sillimanite crucible in a gas-fired crucible furnace at 1250° C for 2 h. This allowed the iron particles to separate downwards through the more fluid slag, and to build up a dense mass of iron, almost slag-free, in the bottom of the crucible.

The final compacting of the porous iron so produced (Fig. 18, *left*) and the removal of some of the remaining slag was brought about by forging at 1100° C.

During the early stages of forging it was essential not to hammer the bloom below about 1050° C, otherwise fragmentation readily occurred. Consequently the initial stages were slow, but as compacting progressed less reheating was necessary and it was possible to forge down to a black heat. Figure 18, *right*, shows a small bloom after forging, and Fig. 19 shows the microstructure of this after annealing. It appears as a fairly typical piece of wrought iron, not unlike that shown by Coghlan[1] from a medieval arrowhead. The carbon content varied from 0·06% to 0·08%.

DISCUSSION OF RESULTS

It was found possible to produce iron by both of the methods used. The amounts produced by the first method, in which a mixture of ore and charcoal was charged, were small and could not be reproduced with any degree of consistency.

Experiments showed that when the hearth temperature was above about 1100° C, reduction of ore lumps charged into the stack was complete some distance above the hearth. Yet when two tuyeres were used, it was never possible to produce an iron-containing product; variations in conditions gave products

Table IV
SLAGGING PROPERTIES OF ORES UNDER REDUCING CONDITIONS

Temperature, °C	Time, h	Result
(a) Newfoundland ore		
900	3	Very friable; crumbles
1000	3	Friable
1050	3	Friable
1100	1½	Friable, reduction incomplete
1100	3	Malleable; slag visible
1150	3½	Malleable; slag visible
(b) Northants ore		
1000	5	Friable, no slag
1050	3	Malleable; slag visible
1100	4	Malleable; slag visible

ranging from individual partly reduced ore lumps, through varying degrees of agglomeration, to one dense, fully fused lump of oxides and slag. Charging an ore–charcoal mixture and using only one tuyere, the production of small amounts of iron was possible, provided that the heat did not exceed about 5 h in duration. Longer times gave the usual wüstite. This suggests that in most cases reduction proceeds to completion but at some later stage reoxidation occurs.

The equilibrium diagram of the iron–oxygen–carbon system[20] indicates that the atmosphere in contact with iron must contain at least 80% of the combustion products in the form of carbon monoxide for iron to remain stable at temperatures between 1000° and 1400° C. If this content is not maintained, wüstite is the stable phase. Work by Mott[21] has shown that this necessary CO/CO_2 ratio of 4 : 1 is not achieved in a fuel bed until the gas has travelled 12–15 fuel-particle diameters from the inlet. Thus with two tuyeres, a charcoal size of 1–1½ in. and a hearth of only 9 in. dia., the gas present in the zone between the tuyeres, the hottest zone in the furnace, consisted almost entirely of carbon dioxide and nitrogen.

Using only one tuyere the oxidizing zone was restricted and the atmosphere in a greater part of the hearth was capable of retaining iron as the stable phase. However, as charcoal was only consumed at or near the tuyere there was a tendency for the burden to move down only one side of the hearth. Here also the ore reduced at higher levels was re-oxidized in the tuyere zone. If the bloom was withdrawn when the last lumps of ore were judged to have reached the hearth, that part of the bloom farthest removed from the tuyere contained some iron. Leaving the bloom in the furnace for longer periods permits reoxidation to occur.

As the burden was only consumed at one side of the furnace, a large part of the burden was stagnant. The ore in such regions was slowly reduced but never reached a temperature high enough to bring about compacting and was consequently useless.

Fig. 18—(*left*) Porous iron after the removal of some of the slag at 1250° C; (*right*) small bloom, after forging

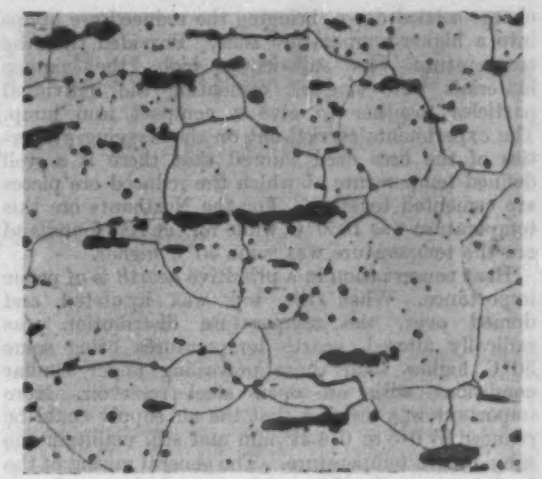


Fig. 19—Microstructure of bloom after annealing. Etched 4% nital × 200

In an attempt to overcome this difficulty the second method was tried, in which the ore was packed in the hearth so that it could be both reduced and compacted. Passing the air through 6 in. of charcoal before it impinged on the ore ensured the necessary carbon-monoxide content of the gas mixture. This was assisted by control of charcoal size and blast pressure, as governed by the tuyere diameter. The blast pressure needed for the best results was found to be very critical: soft blasts did not reach the ore while hard blasts were rich in carbon dioxide when they reached the ore. By crushing the charcoal (in this furnace to ¼ in. size) the necessary carbon monoxide content of the gas could be ensured.

The product obtained by prepacking the ore (*see* Fig. 14) could consist of three parts: reduced, but not compacted ore; compacted iron; and a slag of the fayalite type. The amounts of these three parts varied with the conditions, and either the reduced ore lumps or the iron and reduced ore lumps could be absent. The formation of the slag seemed unavoidable and it was formed very early in the process as a result of some pieces of ore being heated up to about 1200° C before reduction was complete, the wüstite and magnetite combining with gangue materials to form a fluid slag. In many cases, small particles of iron were trapped in the slag, suggesting that in the case of some ore lumps, probably the smaller lumps, reduction had been completed, but the iron was then swept into the slag.

Irrespective of the length of the heat, the free iron content of the slag was always very low, which is completely opposed to Neumann's statement that all iron is formed by reduction of iron oxides present in the slag by particles of solid carbon.

The slag forms in the hottest zone, usually near the bottom of the furnace, although the exact location is ultimately governed by the geometry of the furnace. In cooler zones, higher up the furnace, complete reduction of ore to iron was achieved, and as the slag flowed out across the furnace the remainder of the

charge settled down, bringing the reduced ore lumps into a higher-temperature zone. Provided that the temperature was sufficiently high, the gangue materials were slagged, cementing the individual particles together to give a compact iron lump. The experiments carried out on the slagging properties of the ores used showed that there is a well defined temperature at which the reduced ore pieces are cemented together. For the Northants ore this temperature was 1050° C, while for the Newfoundland ore the temperature was some 50° C higher.

Heat conservation in a primitive hearth is of prime importance. When the top was insulated and domed over, the temperature distribution was radically altered, hearth temperatures being some 50° C higher than those prevailing under similar conditions with an open steel reservoir. More important was the fact that the air supply could be reduced by 0·5 to 0·4 ft³/min and still maintain the same hearth temperature. The general raising of the isotherms up the furnace improved the maximum iron yield, as it meant that more ore could be packed into the furnace and that the amount of reduced but uncompacted ore was lessened.

The iron yield was generally very low. The best figure achieved was ¾ lb of iron from 4 lb of ore, which is about 20% efficiency. The charcoal rate in this case was 16 lb per pound of iron. Large quantities of slag were produced but virtually no cinder. It appears that cinder is only formed in the larger type of furnace and when certain methods of packing the hearth are used. The cinder found at Great Weldon (Northants) was 2 ft in diameter and must have come from a very large hearth. It is probable that a 9-in. dia. hearth, as used in these experiments, was rather too small for the production of this type of cinder; indeed it seemed too small for the successful production of iron when charging an ore–charcoal mixture. Larger hearths would increase the maximum iron yield possible and the ratio of iron to charcoal.

One interesting conclusion reached from these experiments is that slag separation can occur by downwards movement of a liquid phase. At first sight this seems rather surprising, since the slag has a much lower specific gravity (3·72) than the metal, but since the metal is not molten and is cemented by thin films of semi-fluid slag, it is sufficiently rigid to resist the downward forces of gravity, and allows the slag to liquate, just like water from a sponge. On the other hand, during reheating in the crucible for forging, it is the metal that sinks. This is due to the somewhat higher temperatures used, which increase the fluidity and allow the heavier solid particles to fall freely through the lighter slag.

It is doubtful whether there was any attempt to remove the molten slag from the bowl-shaped hearth furnace in the most primitive practice. However, according to Percy's account,[15] slag was tapped from the Catalan hearth, and it is clear that the slag found in Weardale, and shown in Fig. 3 of this report, had also been tapped.

CONCLUSIONS

(1) The complete reduction of ores can be readily achieved in a primitive hearth. Using a mixed charge of ore and charcoal much of the iron produced at higher levels is reoxidized in the tuyere zone and enters the slag.

(2) Prepacking the ore in the hearth gave the best yield of iron, ¾ lb of iron from 4 lb of ore, achieved at a charcoal rate of about 16 lb per 1 lb of iron produced.

(3) A temperature of about 1100° C must be maintained in the smelting zone of the hearth. The actual temperature depends on the ore, and for the ores investigated varied between 1050° and 1100° C.

(4) In a 9-in. dia. hearth a temperature of 1100° C could be maintained with an air supply of 2·3 ft³/min.

(5) Charcoal size is of the utmost importance in ensuring complete reduction. In a 9-in. dia. hearth it was necessary to crush the charcoal to ¼ in. size.

(6) Efficient top insulation gives a more uniform heat distribution and increases the efficiency of the hearth.

Acknowledgments

The authors are indebted to the Consett Iron Co., Ltd., and to Stewarts and Lloyds Ltd. for supplying the Newfoundland and Northamptonshire ores used in this work. The authors are also indebted to their colleagues in the Departments of Metallurgy and Roman-British Archaeology in King's College for helpful assistance and advice.

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The Imatra Thermit Hot-topping Process

Part I—PRACTICE AT THE IMATRA WORKS, FINLAND

By A. I. Aitken, W. C. Fletcher, and G. Fenton

SYNOPSIS

Part I of this report describes the Thermit hot-topping practice used at the Imatra Works in Finland. This practice differs from conventional hot-topping in that the ingot is poured to a lower level in the hot-top and, when solidification is nearly complete, a Thermit powder is added to remelt the metal solidified in the hot-top and fill up the original pipe cavity. The process was observed in operation and was seen to work smoothly and consistently, top discards averaging only 5–6%. Typical results at Imatra are given and the possible application of the process to British practice is discussed.

Part II describes a trial of the Thermit method carried out at the B.I.S.R.A. laboratories in Sheffield, the results confirming the general impressions gained on the Imatra visit. It is concluded that the method is metallurgically sound, with the possible exception of the extent of aluminium pickup, which might restrict the application of the process to steels in which the aluminium content is not critical. Data are presented to serve as a starting-point for works trials in the U.K. 1605

INTRODUCTION

CONVENTIONAL HOT-TOPPING methods in use today all aim to maintain a reservoir of liquid steel at the top of the ingot to feed the shrinkage occurring during solidification. By doing so, the pipe cavity, which would otherwise extend to about halfway down the ingot, can be effectively 'lifted' well up the ingot and the top discard reduced considerably. The most usual hot-topping method makes use of a refractory-lined container or 'hot-top,' which is placed at the top of the ingot mould and retards solidification at that position; the efficiency of this type of hot-top depends very largely on the insulating properties of the refractory used. Recently, very good results have been obtained with hot-top linings of exothermic materials, and there are other and more specialized methods also in use, such as electric-arc and oxy-gas hot-topping. All have one thing in common, however; they maintain a supply of liquid metal in the hot-top during the period of solidification of the ingot body.

The method used at the Imatra Works of Oy. Vuoksenniska Ab. in Finland is based on a somewhat different principle. Here the moulds are fitted with refractory hot-tops, but the steel is teemed to a lower level than in conventional hot-topping. This means that, without further treatment, the pipe cavity would extend below the feeder head and into the ingot body. When solidification is nearly complete, a special Thermit mixture is added to the top of the ingot, and the heat generated by its reaction remelts the metal that has frozen against the walls of the hot-top. This remelted metal, together with the metallic iron yield from the Thermit, fills up the original pipe cavity.

The process was first brought to the notice of the British steel industry in two unpublished reports, circulated by B.I.S.R.A. and containing information supplied by Mr. Berndt Grönblom, Managing Director of Oy. Vuoksenniska Ab. These reports aroused considerable interest, and a few small-scale trials were carried out. Although some promising results were obtained, the general outcome of these trials was rather disappointing; this was probably due to lack of first-hand experience of the method and, at Mr. Grönblom's invitation, the authors (representing two interested steelworks and B.I.S.R.A.) visited the Imatra Works to see the process in operation.

This paper is based on reports SM/B/206/55 and SM/B/71/57 of the Ingots Committee of the Steelmaking Division of the British Iron and Steel Research Association, and was received on 9th July, 1958. The views expressed are the authors' and are not necessarily endorsed by the Committee as a body.

Mr. Fenton is Head of the Steelmaking Division's Sheffield Laboratories, Mr. Fletcher was Chief Works Metallurgist with Stewarts and Lloyds Ltd. until the beginning of this year, when he became General Manager of the Rhodesian Iron and Steel Co., Ltd., and Mr. Aitken is Works Manager at the Dalzell Steelworks of Colvilles Ltd.

HOT-TOPPING PRACTICE AT IMATRA

The steelmaking units at Imatra are four basic electric-arc furnaces working cold-metal/scrap charges. Three of the furnaces are of the conventional Héroult type, two of them tapping 30 tons and the third 12 tons. The fourth furnace is a 3-ton side-electrode Rennerfelt furnace, used mainly for the relatively small output of alloy steel (including stainless steel). The total annual capacity of the plant is about 120,000 ingot tons (metric), mostly in the form of killed plain carbon steels for rails, sections, and concrete reinforcement bar. The Thermit hot-topping process is now in routine use for all killed steels, and up to October, 1957, a total of 398,000 ingot tons had been produced by this method.

During the visit, the teeming and hot-topping of 2-ton (17¾-in. square) and 2¾-ton (18¾ in. × 20¾ in.) ingots were observed. In common with the vast majority of ingots produced, they are bottom-teemed wide-end-up, with twelve 2-ton or ten 2¾-ton ingots on one plate. An interesting point is that, in addition to the normal bottom-teeming arrangements, a spare set is maintained; this can be carried, complete with moulds and ready for use, to any part of the casting bay.

The form of hot-top used is shown in Figs. 1 and 2. No cast-iron headbox is used; the hot-tops are supplied ready-made from a cheap and rather rough type

Fig. 1—Type of hot-top used at Imatra and supplied ready-made

of porous clay brick. They are untapered and have the following dimensions:

	Hot-top for 2-ton Mould	*Hot-top for 2¾-ton Mould*
Inner dimension	11¾ in. square	12⅜ in. × 14⅞ in.
Height	10½ in.	10½ in.
Brick thickness	2⅜ in.	2⅜ in.

The hot-top is light enough to be handled by one man; it is lowered to the desired position in the mould on a simple setting device and fixed with wooden wedges. It is used only once, but is nevertheless more economical than the orthodox superimposed hot-top, owing to the cheapness of the brick used, the reduced labour costs in setting, and the fact that no hot-top maintenance is required. Being held initially by wooden wedges that burn away, it can sink with the ingot during solidification; this obviates hanger cracking and also prevents the formation of a gap between the ingot shoulder and the hot-top, into which the remelted and superheated steel might flow. A further advantage is that the ingot length can be varied because the annular space of about ½ in. between mould and hot-top allows the latter to be set at different heights in the mould. The brick itself, being porous, has fairly good insulating properties and reduces heat loss from the head during solidification of the ingot.

During teeming, the rate of rise is normally 8–9 in./min. When the metal reaches the bottom of the head bricks, teeming is halted for a short while to allow the metal to seal the annular space between the bricks and the mould. When teeming recommences after 15–30 s, a ½-in. layer of vermiculite is added to the ingot top; this has been found beneficial in reducing heat losses. The head is slowly filled to the required height; teeming then ceases and the ' waiting time ' begins, before addition of the Thermit.

The waiting time is one of the two critical factors in the process. If insufficient time is allowed before the Thermit addition and the ingot is still mainly liquid, the main part of the heat generated by the reaction will merely superheat the already liquid metal, which will then pipe after the action has stopped. On the other hand, if the ingot is allowed to approach complete solidification too closely, there is a danger of the first-melted metal running down the cavity and trapping the segregates at the bottom of the pipe. Ideally the Thermit addition should be so timed that most of the heat generated is used in remelting the head metal whilst the last, and most impure, part of the ingot is still liquid. This impure liquid then mixes with the remelted metal and with the virgin metal from the Thermit reaction, and is distributed evenly.

Although the waiting time is described as ' critical,' a tolerance of 2–3 min can be allowed, as the rate of solidification is slow at this stage. To give a rough idea of the waiting time for different sizes of ingot, the Imatra personnel use the following empirical equation:

$$t = 0{\cdot}08x^2$$

where t is the waiting time (min) and x is the smallest cross-sectional dimension (in.) at the top of the ingot, excluding the hot-top. This gives times of 25 and 28 min for the 2-ton and 2¾-ton ingots respectively, although some adjustment may be made according to the type of steel. The form of the above equation indicates that the Thermit addition should be made at a certain stage of solidification. It might therefore be expected that any variations in factors that affect the solidification rate of a given steel (e.g. mould temperature, teeming temperature, teeming rate) would require corresponding corrections to the waiting time, but experience at Imatra shows that these variations in their practice are normally small enough to be taken care of by the permissible tolerance mentioned previously. In other works, however, the practice may differ sufficiently from that at Imatra to make the optimum waiting time significantly different from that given by the Imatra equation. This can be determined only by experience, but it is suggested that the equation will serve as a useful starting point for works trials in the U.K.

The hot-top volumes at Imatra are appreciably less than those in conventional hot-topping practice. For instance, ingots for concrete reinforcement bar (0·35%C) are teemed with 7% hot-top volume and the top discard averages 4½%; ingots for rails (0·5%C) have 9% hot-top volume and an average top discard of 6½%. In general, the higher the quality of the steel, the greater the hot-top volume and the shorter the waiting time, in order to ensure an adequate discard. For all qualities made at Imatra, however, the process has a decided advantage in yield over conventional hot-topping, where hot-top volume is usually about 15% and top discard about 12%, even with the lower-quality steels.

The Thermit reaction starts about 1 min after addition to the ingot top and continues for 2–2½ min (this is the second critical factor and is discussed in the next section). Stripping the ingots begins about 30 min later, using an ordinary ejector plug, and before final removal from the mould the stripper crane knocks off the Thermit slag and adhering bricks to avoid soaker contamination. The ingots are then charged direct to the soaking pits and heated to an average rolling temperature of about 1150° C.

From the pits, the ingots are cogged to about 5 in. square in a 2-high reversing blooming mill. The

bloom returns to the hot shear, where top and bottom crops are taken and, if necessary, required lengths are cut. When required for rails or sections, the hot blooms traverse after cropping to the rail and section mills, which run parallel with the blooming mill. If required for the rod and wire mill, the bloom is cut into short lengths, which are taken to the block stamper for identification and then discharged from the rack to cold stock. Most of the production from the rod and wire mill is in the form of concrete reinforcement bar.

THE THERMIT MIXTURE

The second critical factor in Thermit hot-topping is the burning rate of the Thermit mixture. Compared with a welding Thermit, for instance, the hot-topping mixture should burn quite slowly. If, however, it burns too slowly, insufficient metal will be remelted because of heat loss by conduction to the ingot, mould, and head bricks; on the other hand, if it burns too quickly, too much heat will be dissipated to the atmosphere and again insufficient metal will be remelted. In either case the pipe will not be completely refilled and a greater top crop will be required than with a mixture burning at the optimum rate. This optimum burning rate can be regarded as that which remelts the maximum quantity of head metal, and it is important to achieve this rate if the quantity of Thermit added is to be kept to a minimum.

The correct burning rate and quantity of Thermit in Imatra practice have been ascertained largely by trial and error. The quantity necessary depends not only on ingot size, but also on the cross-sectional area of the hot-top used; the larger the area, the greater the quantity of Thermit required. The best results have been obtained at Imatra with a head in which the cross-sectional area is only about half that of the ingot, and under these conditions the quantity of Thermit required is 1% of the ingot weight; for instance, 20 kg of Thermit are added to the 2-ton ingot. The layer of Thermit powder should burn evenly and regularly from bottom to top, and the 20-kg charge burns completely in about 2½ min. The thickness of the layer in this particular case is about 4 in., and so as a rough guide for works trials it may be considered that a 1-in. layer of Thermit should burn completely in about 40 s.

The burning rate of the Thermit is governed largely by the grading and proportioning of the component ore and aluminium powders. The most pronounced effect is that of the size grading of the aluminium; the smaller the particle size, the more rapidly the Thermit burns. The ore particle size has an opposite and less pronounced effect, the finer ore powders tending to produce a slow-burning Thermit.

The Imatra personnel make no attempt to modify the natural grading of their ore supply, and this grading in fact determines the grading of the aluminium powder used. It is considered advisable at Imatra to carry out regular and routine checks on burning rate so that the aluminium grading can be adjusted if necessary. Another factor with an important effect on the burning rate is the gangue content of the ore. As would be expected, a high gangue content leads to slower burning. In the past, corrections to rapid-burning Thermits at Imatra have often been made by artificially increasing the gangue content by additions of burnt lime.

Fig. 2—Hot-tops wedged in position, ready for teeming on the six-way plate

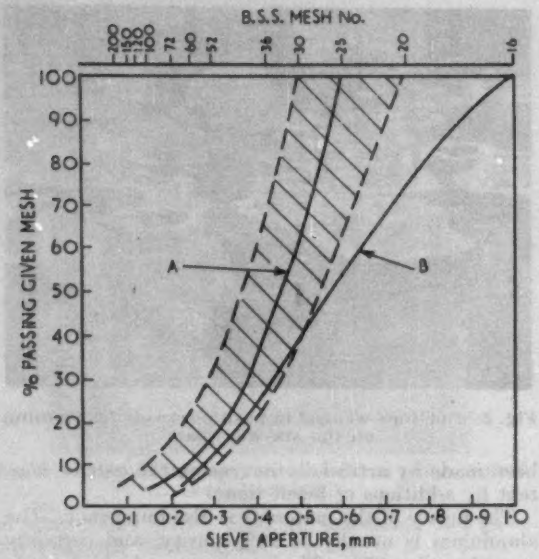
The purity of the materials is also important. The aluminium is usually of 99% purity, and certainly never less than 97%. The iron ore must be high-grade and low in sulphur and phosphorus, to avoid pickup of these elements in the ingot. At the time of the visit, the ore used in the Thermit mixture was Otanmaki ore, containing 65%Fe, 0·14%S, 0·002%P, and about 8% gangue. It is used as-received without an artificial increase of the gangue content. It can be relied upon to be constant in both its composition and its grading, which is of the utmost importance if consistent results are to be obtained.

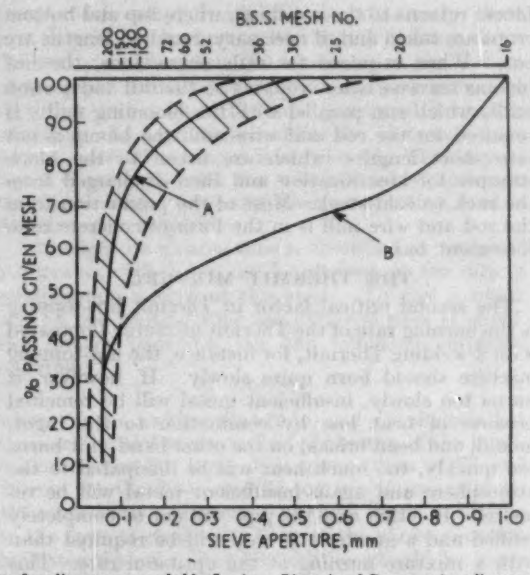
Figures 3 and 4 give the range of gradings of aluminium and ore used at Imatra to obtain a Thermit suitable for hot-topping. At the time of the visit the actual gradings in use were roughly midway between the limits shown (the lines *A* and *B* in these graphs are the gradings used in the B.I.S.R.A. trial—*see* Part II).

In making up the Thermit, the quantities of ore and aluminium used are such that the oxygen content of the ore (considering only iron oxides) and the aluminium are approximately in stoichiometric proportions. As the time of the visit, the graph shown in Fig. 5 was used at Imatra to determine the correct proportions of the Thermit components. It seems logical to suggest that, whenever aluminium pickup has to be minimized, the aluminium content of the Thermit should be kept to the lower limit shown in this graph; this in turn means a high-grade ore containing at least 26½% oxygen if the region of uncertain ignition is to be avoided.

Figure 5 is largely empirical, and recent information suggests that uncertain ignition can be avoided and the lower limit of aluminium content dropped still further, provided that the ore and aluminium are of sufficiently uniform quality and that the newly mixed Thermit is immediately charged into bags to prevent separation of the ore and aluminium powders. However, in the absence of any quantitative information, Fig. 5 is reproduced here in its original form, as it is felt to provide a sufficiently accurate basis for trials.

The ore and aluminium are mixed in an ordinary concrete mixer provided with a cover to reduce dust;





The shaded areas in Figs 3 and 4, bounded by broken lines, represent the range of gradings recommended by Imatra. Lines *A* and *B* represent gradings used in Thermits *A* and *B* respectively (*see* Part II)

Fig. 3—Aluminium grading

Fig. 4—Ore grading

the Imatra personnel state emphatically that with this precaution there is no danger in the operation. The components are measured by weight and the mixing and loading of the Thermit into the charge bags is carried out by one labourer, who can prepare 150 20-kg bags in 3–4 h.

Before filling the bags, two small paper packets containing the fuses are placed in opposite corners at the bottom of each bag to ensure that no matter which way the bag lands in the head, a fuse will fire. Whilst a fuse is not an absolute necessity, if it is omitted there is a danger that the Thermit, when charged on the ingot top, will heat up throughout and then ignite suddenly and violently. The fuse ensures early ignition and uniform combustion of the mixture from bottom to top; during the earlier part of the burning period, therefore, the unignited top layers of Thermit themselves act as an insulating cover and prevent undue loss of heat. The weight of each fuse used is 20–25 g, consisting of a 50 : 50 mixture of aluminium powder and either KNO_3 or $NaNO_3$, all passing 200 mesh.

After filling, the bags are tied securely at the neck and placed in a closed metal box, large enough to hold sufficient bags for one heat. The box is transported to the casting pit and not opened until the time for addition to the ingot tops.

RESULTS OBTAINED AT IMATRA

Thermit hot-topping is now standard practice for all killed steels at Imatra, and a routine procedure has been established. Observations of the process in operation, from the tapping of the furnace to the rolling and cropping of the billets, showed that the whole sequence works quite smoothly. The Thermit charges can be handled by one man, so that their addition to the ingot tops is a very simple procedure.

A number of sectioned ingots and billets and the corresponding sulphur prints were examined. The ingot tops were characteristically flat or slightly dished (*see* Fig. 6), sometimes with a very small residual cavity wholly contained in the head. In each case the ingot body was quite sound and a noticeable feature was the near absence of areas of major segregation such as are invariably associated with pipe cavities in conventional hot-topping.

In some of the ingot sections, the shape of the original pipe cavity could be detected as a vague outline. In a number of places, however, dendrites could be seen to have grown across this outline, and obviously diffusion had taken place. The presence of this outline does not appear to be a source of weakness and is not considered detrimental. It could certainly not be detected in the rolled billet. Examination of the billet sections confirmed that the small top crops were adequate, having regard to the particular steel quality in every case, and sufficient to clear piping and any major segregation.

The quality of the metal filling the original pipe

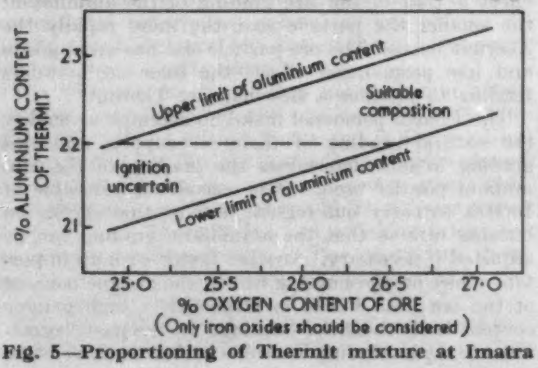

% ALUMINIUM CONTENT OF THERMIT
Upper limit of aluminium content
Suitable composition
Ignition uncertain
Lower limit of aluminium content
% OXYGEN CONTENT OF ORE
(Only iron oxides should be considered)

Fig. 5—Proportioning of Thermit mixture at Imatra

cavity was discussed and many analyses were quoted. In general the analysis and inclusion content of the feed metal did not differ significantly from that of the ingot; the main difference was in the carbon and manganese contents of the feed metal, which tended to be slightly lower, but only by 0·03–0·04%. This is attributable to dilution caused by the virgin-metal yield of the Thermit. The 10-kg charge to a 1000-kg ingot, for instance, will produce 5 kg of iron; at the same time it will remelt 30 kg of the ingot-head metal and will mix with both this remelted metal and with the still-liquid interior of the ingot. The Imatra personnel claim—and the analyses verify—that any dilution effect is only noticeable on highly alloyed steels. In this connection their experience with the Thermit method is rather limited, owing to the relatively small output of such steels. At that time their practice for alloy steels did not differ materially from that adopted for carbon steels, the same Thermit being used; they agreed, however, that there was no reason why the mixture should not be modified, by the addition of suitable ores or ferro-alloys, to give a metallic yield more closely approaching the composition of the ingot.

The question of aluminium pickup by the feed metal was also discussed. The following figures quoted by Imatra indicate the order of pickup at different distances down the ingot when using Thermit mixtures proportioned roughly midway between the limits of Fig. 5:

Distance down ingot	15%	8%	6% (approx. discard level)
Al pickup	0·01%	0·015%	0·04–0·05%

Although the pickup appears to be largely confined to the head metal, it could still be detrimental with certain types of steel. It should be possible, however, to reduce these figures by careful proportioning of the Thermit, but unfortunately no information is available on the minimum pickup attainable. It may be, therefore, that the method will be found inapplicable to steels in which the aluminium content is critical. The extent of aluminium pickup is one of the factors that must be studied in detail in trials of the process in the U.K.

The production records from the rolling mill were made available, and ten daily records from recent production were selected at random and copied. All details relating to the rolling of every killed-steel ingot during those ten days were extracted and are summarized in Table I. A total of 235 ingots of five different qualities was involved; the top crop averaged only 5·3% and the yield (cast ingot to sound billet) for the whole ten days' production exceeded 90%. Examination of the individual records showed that the top crops were reasonably consistent, both from cast to cast and from ingot to ingot within one cast. The histogram in Fig. 7 shows the distribution of top-crop percentages over the 235 ingots.

It was admitted that, in routine practice, an occasional ingot failed to show complete success, and in these cases the pipe was often deep, necessitating a top discard of about 15%. This, however, was so rare that little importance was attached to it. Only four of the 235 ingots mentioned previously required top discards exceeding 8%, maximum 11·7%.

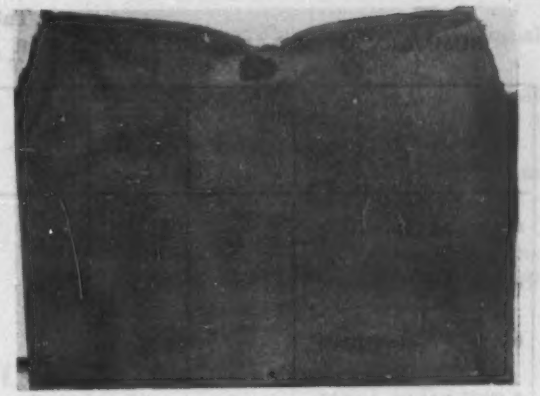


Fig. 6—Section of top part of typical Imatra ingot

APPLICATION TO BRITISH PRACTICE

As a result of their visit, the authors are satisfied that the Thermit hot-topping process, as practised at Imatra and with respect to the Imatra steel qualities and casting conditions, fully merits the claims that have been made for it. They feel that the results obtained by this method are at least as reproducible as those by conventional hot-topping methods, and that the small top crops taken from the rolled billets are sufficient to clear piping and segregation and leave sound material. There appears to be no real reason why the process should not be equally successful in the U.K., at least for similar steel qualities. In the case of certain types of steel in which the aluminium content is critical, it may be found that the method cannot be applied owing to aluminium pickup from the Thermit addition. More evidence is needed on this.

Strictly speaking, Imatra's experience has proved the Thermit process only for plain carbon steels, bottom-teemed into wide-end-up ingots not exceeding 2¾ tons in weight. However, it should be possible by slight modification to the basic process to apply the method to other conditions.

The question of alloy steels has already been mentioned. Whilst the Thermit mixture could no doubt be modified to give a metallic yield more closely approaching the composition of the alloy steel, it may also be found necessary to adjust the waiting time and proportion of Thermit to allow for the different solidification characteristics of alloy steels, particularly those which are highly alloyed.

The application to top-teemed ingots should not produce any major difficulty. The pipe cavity in a top-teemed ingot tends to be slightly greater in volume than that in a bottom-teemed ingot, as the former is filled more rapidly and hence a smaller proportion of the ingot has solidified at the end of teeming. For this reason it may be necessary to use a slightly greater proportion of Thermit on a top-teemed ingot.

Application to narrow-end-up (N.E.U.) ingots is again a factor on which Imatra has had no experience, but the authors can see no reason why the process should not work equally well in such cases. There is, perhaps, a danger when the mould configuration is such that a distinct secondary pipe is formed; the

Table I

SUMMARY OF ROLLING-MILL DATA FOR 10 DAYS' PRODUCTION OF KILLED STEELS AT IMATRA

Quality	No. of Ingots	No. of Casts	Ingot Weight, tons	Average Losses, %				Ingot-to-Billet Yield, %
				Top Crop	Bottom Crop	Other Rejects	Scale Loss	
0·10%C, 0·4%Mn, 0·25%Si	145	13	2½	5·5	1·8	1·2	1·3	90·2
	20	2	2½	5·9	1·8	1·5	1·3	89·5
0·15%C, 0·4%Mn, 0·25%Si	30	3	2½	4·7	1·8	0·1	1·3	92·1
0·35%C, 0·5%Mn, 0·25%Si	11	1	2½	2·9	1·7	8·3	1·3	85·8
	20	3	2½	4·5	1·2	Nil	1·3	93·0
0·45%C, 0·8%Mn, 1·6%Si	6	3	2	8·7	2·3	Nil	1·3	87·7
0·55%C, 0·8%Mn, 1·7%Si	3	2	2	6·3	1·7	Nil	1·3	90·7
Overall Summary	235	27	2–2½	5·3	1·7	1·3	1·3	90·4

Thermit action might melt the intervening metal and link up the primary and secondary pipes. Such an occurrence, however, is felt to be very improbable with most N.E.U. practices, but if it is found to be the case, an increase in waiting time should help to overcome the danger. A further characteristic of N.E.U. ingots is that the primary pipe tends to be smaller in volume than that in a wide-end-up ingot, so that it should be possible to reduce slightly the proportion of Thermit required.

In theory there is no limit to the size of ingot to which the process could be applied. In the opinion of the Imatra personnel, a slight increase in the proportion of Thermit may well be necessary as the ingot size is increased above 2¾ tons, the limit of their experience.

The type of hot-top used must also be considered. For instance, the Imatra brick is porous and more insulating than normal British hot-top materials; a typical British hot-top would therefore permit more heat loss during the waiting period and consequently more Thermit would be required to melt the necessary quantity of metal. Furthermore, the Imatra personnel state that the quantity of Thermit required is roughly proportional to the cross-sectional area of the head at the height at which the reaction occurs. In the Imatra head, which is untapered, this area is only about 45% of that of the ingot top; if the area of the head, which in U.K. practice is usually tapered, exceeds this figure at the height to which it is teemed, an increased Thermit quantity is again likely to be required. However, taking all these factors into account, the Imatra staff feel it is unlikely to exceed 1¼% of the ingot weight, compared with 1% in their own practice.

There are obviously other factors, some peculiar to particular works, that will also have to be taken into account. For instance, it is unlikely that the idea of a hot-top which is usable only once will be readily acceptable in the U.K. where time and space considerations often make a long hot-top life almost essential. The Thermit reaction might have a detrimental effect on the life of the type of head brick normally used in U.K. practice, which must be taken into account in the overall economic picture. Again, the Thermit process may necessitate a slight delay in stripping, which could have a detrimental effect on both mould life and the production flow. Some works may also find difficulty in achieving the necessary teeming control for maximum increase in yield, particularly with ladles considerably larger than the 30-ton type used at Imatra.

How far the process is practicable and economical at any particular works can therefore be assessed only by trials at the works in question, and undoubtedly these trials would entail much experiment to decide the optimum practice. Nevertheless, once the practice has been standardized, as at Imatra, it is attractive not only in its efficiency but also in its simplicity, and Thermit hot-topping fully merits serious consideration in the U.K.

SUMMARY AND CONCLUSIONS

The authors have observed the Thermit hot-topping process in operation at the Imatra Works in Finland. It was seen to work smoothly and consistently, to be simple in operation, and to reduce top discard to very attractive levels. The process appears to be metallurgically sound, with the possible exception of

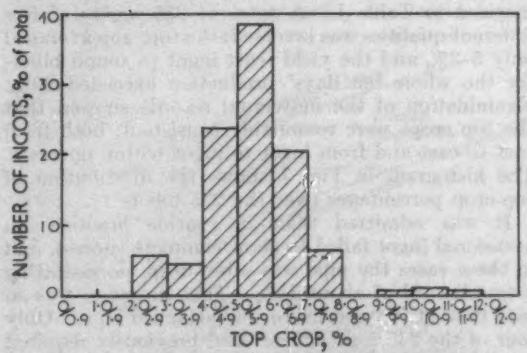


Fig. 7—Distribution of top discards at Imatra

aluminium pickup, which may restrict its application to steels in which the aluminium content is not critical.

The actual details of the Imatra practice have been evolved to meet their particular conditions, and obviously different conditions will require some modification to the process as practised at Imatra. Only full-scale trials will allow the optimum practice to be set down for a particular works, but the following details should provide a useful starting point:

(i) The Thermit mixture should be graded and proportioned according to the data given in the present report

(ii) The quantity of Thermit added in the initial trials should be 1% of the ingot weight

(iii) The head should be teemed to 7–9% as-cast volume and the heat loss minimized by applying a thin layer of vermiculite

(iv) The waiting time should be calculated from the equation

$$t = 0{\cdot}08x^2$$

where t is the waiting time (min) and x is the smallest cross-sectional dimension (in.) at the top of the mould.

Part II—TRIAL AT B.I.S.R.A. LABORATORIES, SHEFFIELD

By G. Fenton

INTRODUCTION

FROM THE INFORMATION gained on the visit to Imatra, it was concluded that the Thermit hot-topping method was metallurgically sound, at least in connection with the types of steel made there. There appeared to be two main critical factors in the process: first, the waiting time before addition of the Thermit, and secondly, the burning rate of the Thermit mixture. These factors are discussed in detail in Part I. As a result of many trials, the Imatra personnel have assessed both factors empirically and standardized them for their own conditions.

To meet different conditions at other works, it is very likely that some modifications in detail, though not in principle, will be required; their extent can be assessed accurately only by full-scale works trials. However, it is felt that good approximations, to serve as a starting point, can be obtained from the data given in Part I.

As a preliminary to full-scale trials, a trial at the B.I.S.R.A. laboratories in Sheffield was arranged, and is described below. Its main object was to verify the general impressions gained on the Imatra visit and to check further on some of the metallurgical aspects of the process.

EXPERIMENTAL PROGRAMME

The burning rate of the Thermit mixture appears to be critical. It is controlled very largely by the gradings of its component ore and aluminium powders; it should be realized, however, that for obvious reasons of convenience no attempt was made at Imatra to modify the natural grading of their ore supply, and alterations in burning time were made by varying the grading of the aluminium. Similarly, it would be impracticable for any steelworks taking up the process to attempt to match the Imatra ore grading exactly; rather should the natural grading of the particular ore supply be accepted and the aluminium grading modified to suit it.

With this point in mind, it was decided to cast two ingots in this trial. On one ingot, the Thermit mixture was made as closely as possible to Imatra specification, and on the other the natural grading of the ore available at B.I.S.R.A. was used and the aluminium grading was modified in an attempt to produce a Thermit burning at the same rate as the Imatra Thermit. Apart from this difference, all other conditions would be reproduced as closely as possible, the two ingots being cast from the same heat.

The steelmaking unit at B.I.S.R.A. is a 10-cwt electric-arc furnace, so that the two ingots were restricted to 5 cwt each. The mould used is of wide-end-up plug-bottom design, and its internal dimensions are 9-in. square top, 8¼ in. square bottom, 27 in. long.

Type of Hot-top Used

The hot-tops currently in use at Imatra are square in section, untapered, and made from a cheap and rather rough type of porous clay brick (*see* Figs. 1 and 2); they are used only once. There are two main reasons why a similar system would not generally be used in U.K. practice; first, there does not appear to be a porous brick in this country equivalent in cost to the Imatra brick, and secondly, a hot-top that can be used only once is not favoured in most works because of time, space, and convenience considerations.

For these reasons, the hot-tops in this trial were made of firebrick, the usual hot-topping refractory in the U.K. In all other respects, however, the Imatra recommendations on shape and size were followed; the hot-tops were made square in section, untapered, and 6¼ in. square internally. As the ingot itself is 9 in. square, the cross-sectional area of the hot-top was about 52% of that of the ingot, which conforms generally to the Imatra recommendation. It was planned to teem them to a 4-in. level, equivalent to 8½% of the total cast volume, and to add a thin layer (¼ in.) of vermiculite granules to each, immediately after teeming.

One further deviation from Imatra practice was in the quantity of Thermit applied. As the firebrick used in the trial hot-tops is less efficient thermally than the porous Imatra brick, it was felt that the 1% proportion recommended by Imatra might be insufficient. The proportion was, therefore, increased in this trial to 1½% of the cast weight.

Details of Thermit Mixtures

In making up the Thermit mixtures, use was made of Figs. 3, 4, and 5. It seems logical to suggest that, if aluminium pickup is to be minimized, the aluminium proportion should be kept to the lower limit of Fig. 5.

If the region of uncertain ignition is to be avoided, this in turn means that a high-grade ore containing at least 26½% oxygen (combined as iron oxide) is required. After a number of enquiries, it was decided that the most suitable ore for these trials which was readily available was an Itabira ore; this is an extremely pure hematite containing 29·4% available oxygen and only 2% gangue. The analysis supplied was as follows:

Fe_2O_3	Fe_3O_4	MnO	SiO_2	CaO
90·85%	1·15%	0·026%	0·47%	0·07%
	Al_2O_3	P_2O_5	S	
	0·45%	0·034%	0·005%	

Figures 3 and 4 relate to the ore used at Imatra, which contains about 8% gangue; as mentioned in Part I, the quantity of gangue has an important effect on the burning rate. To simulate the Imatra ore more closely, the Itabira ore was modified by additions of 3% sand and 3% lime, bringing its gangue content up to 8% and reducing the available oxygen to 27·05%. Making use of Fig. 5, this oxygen level means that the Thermit mixture should contain 22·3% of aluminium and 77·7% of the modified ore. For the purpose of the trial, a batch of aluminium powder to Imatra specification was obtained from the Imatra suppliers.

The Thermit used on the first ingot (Thermit *A* and ingot *A*) was made to Imatra specification. The aluminium powder could then be used as-received, but the modified Itabira ore had to be sieved to the correct grading. The gradings of aluminium and ore are shown by the lines marked *A* in Figs. 3 and 4; they fall well within the recommended limits, shown by the shaded areas.

Thermit *B*, used on the second ingot (ingot *B*) was made with the as-received grading of the modified Itabira ore. As shown by line *B* in Fig. 4, this is coarser than the Imatra ore. This, according to Imatra experience, would have the effect of accelerating the reaction; to counteract this, the aluminium should also be coarser. The choice of the aluminium grading for Thermit *B* was quite arbitrary and is shown by line *B* in Fig. 3.

A 7½-lb quantity (1½%) of each Thermit was made up, with the proportions of 77·7% ore and 22·3% aluminium, and placed in paper bags. A 20-g fuse, made to the Imatra recommendation, was placed at the bottom of each bag. This quantity of Thermit in the 6½-in. square hot-top gave a layer about 2 in. thick; thus, according to the Imatra data, a total burning time of 1 min 20 s would denote the optimum burning rate.

The waiting time adopted was 6½ min for both ingots, derived from the application of the formula $t = 0{\cdot}08x^2$ to the case of a 9-in. ingot.

Casting Details

The steel used in this trial was plain carbon, silicon-killed, and had the following pit analysis:

C	*Si*	*Mn*	*S*	*P*	*Al*
0·50%	0·40%	0·62%	0·036%	0·059%	0·01%

The furnace was tapped at 1600° C into a preheated ladle, and the ingots were top-teemed with a rate of rise of about 1 in./s. A pit sample was taken between the two ingots. Ingot *A* was teemed accurately to the desired 8½% level, but ingot *B* was inadvertently teemed slightly high, to about 10% volume.

The time log of the trial was as follows:

	min	*s*
Gas preheat off ladle	zero	
Start tap	2	50
Finish tap	3	33

	Ingot A		*Ingot B*	
	min	*s*	*min*	*s*
Start teem	4	47	6	07
Finish teem, vermiculite added	5	15	6	37
Thermit added	11	45	13	07
Thermit reaction started	12	05	13	38
Thermit reaction finished	13	30	14	20

The burning time for Thermit *A* was 1 min 25 s, and for Thermit *B* 0 min 42 s; i.e., Thermit *B* burned twice as quickly as Thermit *A*. Thus the latter, produced to Imatra specification, behaved as expected, but the attempt to produce a similar burning rate in Thermit *B* was not very successful.

EXAMINATION OF THE INGOTS

The ingots were allowed to go cold in the moulds before stripping. The hot-tops were removed carefully; both sets of bricks showed evidence of attack and erosion by the Thermit slag. The hot faces were also cracked and flaky, and in general the damage to the bricks was considerably greater than that occurring to firebrick hot-tops used conventionally on these ingots.

Sulphur Prints

The tops of the two ingots were sawn off at a depth of about 7 in. below the shoulder and then sectioned longitudinally to the centre-line. Both ingots showed a small pipe cavity wholly contained in the head metal, that in ingot *B* being slightly the smaller of the two and being covered by a thin bridge of metal.

Sulphur prints of the sections are shown in Fig. 8. There was pronounced central unsoundness near the base of each section. This, however, is typical of ingots made in these moulds and invariably finishes at about the same level, no matter what type of head is used—firebrick, insulating brick, exothermic tiles, or Thermit. It is attributed to insufficient mould taper and not to any characteristic of the feeder head. Apart from this central looseness, the sulphur prints are quite satisfactory and show very good feeding; it is noticeable that the small remaining pipe cavities have no associated major segregation. The outline of the original cavity in ingot *A* is extremely difficult to trace, but can be discerned on the sulphur print of ingot *B* owing to the slightly lighter shade shown in the print by the metal filling the cavity. Judging purely from the sulphur prints, discards that just cleared the pipe cavities would be quite adequate if the sound metal in the heads were useable; these discards would be 5·1% for ingot *A* and 5·4% for ingot *B*. The discards necessary to clear the whole head portions would be 5·9% for ingot *A* and 7·4% for ingot *B*, the appreciable increase in the latter being due solely to the fact that the head was inadvertently filled too high.

Chemical and Spectrographic Analysis

As a check on the analysis of the feed metal, spot analyses were taken at five positions in each ingot, as shown in Fig. 8. Positions 1–3 were on the centre-line, 1 being at shoulder level and 2 and 3 at 2-in. intervals below it. Positions 4 and 5 were near the outside of the ingot. The analyses obtained are given in Table II.

Both sets of analyses are very similar. Positions 2, 3, 4, and 5 are not significantly different from the pit sample, but position 1 in both ingots shows dilution of carbon, manganese, sulphur, and phosphorus, slight pickup of silicon, and appreciable pickup of aluminium. The dilution effect is more strongly marked in ingot *B* than in ingot *A*. With the possible exception of the dilution of manganese in ingot *B*, only the pickup of aluminium can be considered serious. It is apparent from Table II that the great majority of this pickup is in the form of soluble aluminium.

To study more closely the variation in aluminium content down the ingots, spectrographic traverses for aluminium were taken between positions 1 and 2. The results are shown in Table III, the distance down the ingot being quoted as percentage discard.

Table III shows that aluminium pickup extends below the shoulder and to an extent that would be inadmissible with certain types of steel. The effect is more pronounced in ingot *B* than in ingot *A*.

Micro-examination

Micro-examination was confined to positions 1 and 2 in ingot *A*. Both positions showed typical as-cast structures very similar to each other, except that position 1 showed more free ferrite. This would be expected owing to the dilution effect of the Thermit metal.

The sample from position 1 contained slightly more alumina inclusions than that from position 2 (confirming the insoluble aluminium figures in Table II), but on the other hand position 1 showed slightly fewer sulphide inclusions, again owing to the dilution effect. Both types of inclusion in both samples were small and well dispersed, and there was no evidence of segregation of inclusions. There was no noticeable difference in the form of the inclusions in the two samples.

A.S.T.M. grain-size determinations were also carried out by the McQuaid–Ehn method on samples taken from points adjacent to positions 1 and 2. Position 2, which showed no aluminium pickup, had a grain size of 3–5; position 1, with heavy aluminium pickup, had a grain size of 7. These results confirm that the extent of aluminium pickup observed in these ingots would be undesirable in grain-controlled steels.

DISCUSSION

The examination of the ingots by sulphur-printing, analysis, and micro-examination has shown that the Imatra process is metallurgically sound, with the possible exception of aluminium pickup. Table III shows that, even allowing for the extra metal in the head of ingot *B*, aluminium pickup is more pronounced in ingot *B* than in ingot *A*. As both Thermit mixtures would produce the same quantity of virgin iron, the reason for this must be that Thermit *A* remelted more head metal than Thermit *B*; this is supported by the

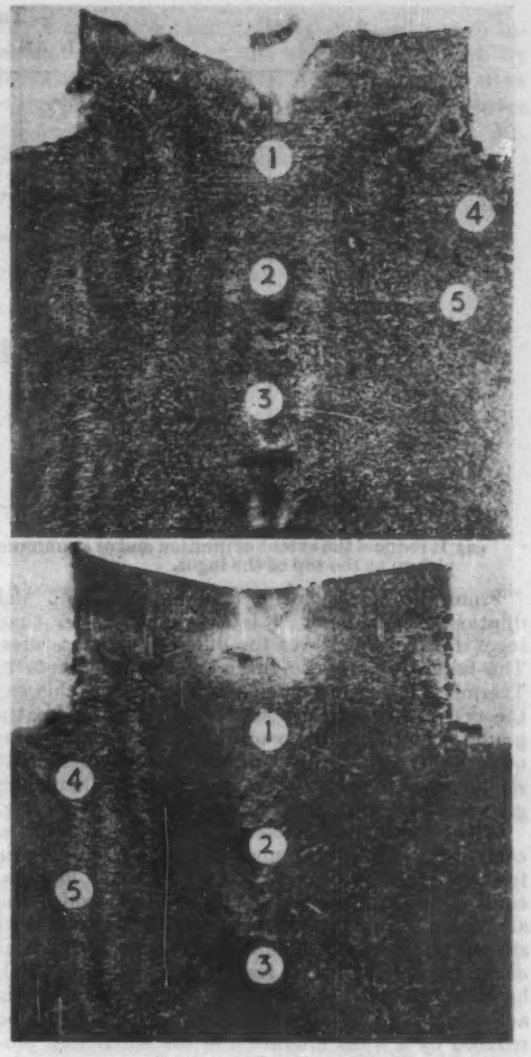


Fig. 8—Sulphur-prints of (top) ingot *A*, (bottom) ingot *B*

fact that the small remaining cavity in ingot *A* is slightly bigger than that in ingot *B*, indicating that the volume of liquid metal remaining after the Thermit reaction was greater in ingot *A*. However, it is obvious from the sulphur prints that Thermit *B* remelted an adequate quantity of metal, and so the quantity of metal remelted by Thermit *A* was more than adequate. Thus the results of the present trial show that the increase in the Thermit proportion to 1½% was unnecessary.

The optimum burning rate of the Thermit can be considered as that which, for any given weight of Thermit, results in the maximum quantity of head metal being remelted. It is apparent that this optimum should be approached as closely as possible for two main reasons:

(i) It enables the minimum quantity of Thermit to be added, thus minimizing the cost

Table II

CHEMICAL ANALYSES OF INGOTS

Position		C, %	Si, %	Mn, %	S, %	P, %	Total Al, %	Soluble Al, %	Insoluble Al, %
Pit sample		0·50	0·42	0·62	0·036	0·059	0·010		
Ingot *A*:	1	0·44	0·45	0·59	0·032	0·050	0·061	0·071	0·010
	2	0·47	0·42	0·60	0·034	0·056	0·010	0·005	0·005
	3	0·48	0·42	0·62	0·036	0·054	0·008		
	4	0·49	0·42	0·63	0·037	0·060	0·008		
	5	0·48	0·42	0·64	0·037	0·058	0·010		
Ingot *B*:	1	0·44	0·44	0·52	0·030	0·047	0·061		
	2	0·50	0·43	0·63	0·034	0·055	0·010		
	3	0·51	0·43	0·64	0·037	0·059	0·020		
	4	0·49	0·42	0·63	0·037	0·058	0·018		
	5	0·50	0·43	0·63	0·037	0·056	0·013		

(ii) It reduces the extent of dilution and of aluminum pickup at the top of the ingot.

From the standpoint of aluminium pickup and dilution effects, ingot *A* is noticeably better than ingot *B*, solely owing to the different burning rates. The failure to produce the correct burning rate in Thermit *B* is not considered a serious fault, as this was the first attempt to use any other than the Imatra gradings and the choice of aluminium grading was quite arbitrary. A series of small-scale experiments should very quickly allow the correct aluminium grading to be selected for any particular ore grading.

When considering steels in which the aluminium content is not of prime importance, the results of this trial appear very promising, and relatively low discards would be possible. With steels in which the aluminium content is critical (e.g. grain-controlled steels), the extent of aluminium pickup in this trial could be serious. The results of this single trial, however, should not condemn the process on this account, as the aluminium pickup could probably be reduced by a small alteration in the aluminium proportion in the Thermit. There is also no certainty that Thermit *A* did, in fact, burn at the correct rate; all that is certain is that its burning rate was much nearer the optimum than that of Thermit *B*.

As mentioned in Part I, recent information from Imatra (received since this trial was carried out) suggests that the aluminium content of the Thermit can be safely dropped below the lower limit of Fig. 5 without danger of uncertain ignition, although no quantitative information is available as yet. This tends to support the view that the extent of aluminium pickup observed in this trial could be reduced by slight adjustment of the Thermit mixture.

CONCLUSIONS

The present trial has confirmed, in the following respects, the impressions gained from the Imatra visit:

(1) In general, the principle of the Thermit method appears to be sound. Both ingots fed extremely well, and the only drawback of any major importance was in the extent of aluminium pickup. It is quite likely, however, that this could be reduced by slight modification to the Thermit.

(2) The burning rate of the Thermit is critical, not so much from the point of view of adequately filling the pipe cavity, but from the points of view of minimizing dilution, aluminium pickup, and quantity of Thermit required.

(3) The grading of the components has a pronounced effect on the burning rate of the Thermit. The preliminary attempt to produce a suitable Thermit using the natural grading of the available ore supply (Thermit *B*) was not very successful, but simple laboratory tests on trial batches of Thermit should enable any particular ore grading to be matched by a suitable grading of aluminium. A 1-in. layer of Thermit should burn completely in about 40 s.

(4) A quantity of Thermit equivalent to 1½% of the cast weight is more than adequate; the Imatra recommendation is 1%.

A point that should be taken into account in assessing the economics of the process is that it is

Table III

SPECTROGRAPHIC ANALYSES OF INGOTS

Ingot *A*		Ingot *B*	
Discard, %	Total Al, %	Discard, %	Total Al, %
5·9	0·092 Position 1 (shoulder)	7·4	0·095 Position 1 (shoulder)
7·7	0·090	8·4	0·090
8·6	0·073	9·4	0·088
9·6	0·041	10·2	0·068
10·4	0·027	11·2	0·046
11·5	0·017	12·3	0·036
12·3	0·011	13·1	0·027
14·1	0·008 Position 2	14·7	0·006 Position 2

likely to reduce the life of ordinary firebrick heads very seriously. In general, however, the results of the trial are promising and suggest that further and more extensive works trials are desirable.

Acknowledgments

The authors wish to record their gratitude to Mr. Berndt Grönblom and his staff, who gave invaluable assistance, both by discussion and by demonstration in the works, during this assessment of the Imatra method. The authors also acknowledge the permission to publish this report, given by Mr. Grönblom and by their respective organizations.

A Review of Methods for Assessing Non-metallic Inclusions in Steel

By T. R. Allmand, L.I.M.

SYNOPSIS

A critical review has been undertaken of the methods available for assessing non-metallic inclusions in steel. Microscopic, microradiographic, and magnetic methods are fully described, together with typical inclusion-count results obtained by some of these methods. The main factors affecting the results of inclusion counts—effect of rolling, method of sampling, type of microscope used, and selection of field to be examined—are briefly discussed, with examples where possible. It is shown that inclusion-count indices obtained by some well known current methods do not give all the information called for by present-day requirements of cleanness. Recommendations are made for the use of some of the existing methods on a more scientific basis so that more reliable and reproducible results can be obtained. 1525

INTRODUCTION

THE PROBLEM of non-metallic inclusions in steel has become prominent in recent years. Until the advent of high-strength steels for aeroplanes, transfer machinery, and automation, inclusions in steel were considered to be only a mild trouble-maker. Nowadays, consumers are becoming inclusion-conscious, not only because of the stringent demands for aero-quality steels, but also because the costly automatic-transfer machinery is so efficient that it is often not possible to tolerate batch differences in quality previously acceptable commercially. Where large tonnages of steel are being handled, as in automation processes, holdups due to lack of feed or speed adjustment, resulting in breakdown of tooling setups, can cause havoc in a large machine shop, and it is for these and other reasons that a degree of control over inclusions—their size, distribution, and type—is necessary. In view of this, it seems desirable that the methods of assessing inclusions in steel should be reconsidered, the prime object of this review.

By reviewing the methods available in a comprehensive way, the advantages and disadvantages of each method can be clearly brought out, thus permitting the use of methods that are capable of yielding the maximum information. It is felt that this review will be of value to the new worker in this field, and also that it will prevent the duplication of techniques and the development of techniques that are not entirely satisfactory.

The methods of assessment now available can be divided into four distinct groups: (i) microscopic methods based on comparison with, say, standard charts; (ii) microscopic methods that involve direct counting and possibly measurement of inclusions; (iii) microradiographic methods that involve taking a radiograph of a known volume of sample and studying the size, shape, and distribution of inclusions in it; and (iv) magnetic methods that involve magnetizing the sample and studying the 'inclusion indications' on it, from which an assessment can be made of the inclusion content in the steel.

These methods, however, are dependent to a great extent upon the condition of the sample, the method of sampling, the type of microscope used for determining the counts, and the method of selecting the fields to be examined. In view of this, it was found necessary to discuss these factors briefly in a section preceding the review of methods for assessing inclusions in steel.

FACTORS AFFECTING RESULTS OF INCLUSION COUNTS

The most important factors affecting the results of inclusion counts are:

(1) Effect of mechanical working
(2) Sampling
(3) Preparation of sample
(4) Microscope
  (*a*) Magnification
  (*b*) Field of view
(5) Selection of field of view.

Effect of Mechanical Working

When steel is hot-worked by rolling or forging, the inclusions are strung out in the direction of working.

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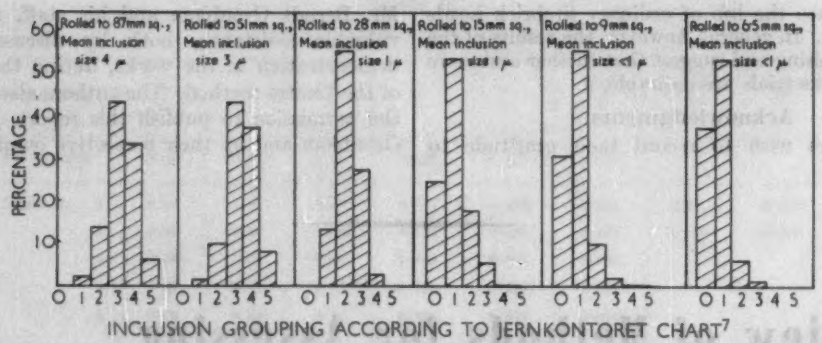

Fig. 1—Effect of rolling on inclusion-count results for sulphides. Ingot size 37·2 cm (13 in.)

Hard and refractory inclusions retain their shape and particle size, refractory and brittle ones break up and the particles of inclusion are strung out, and plastic ones are elongated and rolled out to some extent with the steel. Alumina inclusions are generally of the first type, silicate-glass inclusions are in the second or third class, depending on their constitution, and sulphides are usually plastic.

The size of the sample indicates the degree of reduction of the material from ingot to bar. With increasing reduction, plastic inclusions change their shape and therefore their size, whilst the harder types of inclusions are not affected by reduction. It is clear, therefore, that inclusion counts obtained by methods based on comparison of the inclusions with standard charts will be subject to variations if the degree of reduction from ingot to bar is not standardized.

The influence of rolling on the results of inclusion ratings obtained by the well known Jernkontoret method is shown in Figs. 1 and 2. The inclusion numbers for the plastic type (Fig. 1) are altered as the degree of reduction from ingot to bar is varied, whilst the rating for the non-plastic types (Fig. 2) is hardly affected by changes in reduction.

Sampling

Steel ingots produced commercially are heterogeneous in nature. The exact distribution of the non-metallic inclusions in an ingot is not known, but experience suggests that it could vary from the top to the bottom and also from the centre to the outside of an ingot. Differences between ingots in the same cast have also been observed. The magnitude of these differences is largely dependent on steelmaking and casting conditions, a full discussion of which is outside the scope of this review.

As with all methods that aim at obtaining the average composition of a heterogeneous material, sampling procedure is of great importance. Two methods of sampling are advocated: *random sampling*, in which selection of the material is done in such a way that every portion of the bulk has an equal chance of appearing in the sample, or *representative sampling*, in which the sample is deliberately taken in a systematic way so that each portion of the sample represents a corresponding portion of the original bulk. The latter method is often used when it is known or suspected that variations exist between the various portions of the bulk.

Random sampling is best achieved by numbering the samples and then choosing the numbers of those to be included in the sample by some random method. The numbers can be drawn from a table of random numbers, such as that given by Fisher and Yates,[1] or they can be drawn out of a hat.

Representative sampling is best achieved by taking samples equally spaced throughout the bulk. Often this method of sampling is perfectly satisfactory, but departure from random sampling introduces a possibility of bias. Individual sampling schemes of this type must, therefore, be carefully examined before being adopted.

Preparation of Sample

Normal polishing techniques used in metallography for examination of structures are unsatisfactory for inclusions, because inclusions are easily dragged out of the steel, and other polishing defects, such as scratches, pits, etc., easily result if certain precautions are not taken during polishing. These defects show up at low magnification as dark spots, which could be mistaken for inclusions. Moreover, such defects make the estimation of inclusions exceedingly difficult.

Good, clean surfaces can be obtained only by experience, and it is impossible to give exact details of the polishing operation, since this is connected with the type of steel being polished, the kind of polishing paste used, the amount of pressure applied to the specimen at all stages of preparation, the condition of the cloths on the wheels, and the amount of time spent on the wheels. However, it would be found advantageous, when conventional polishing methods are used, to bear in mind the following:

(*a*) Pileless cloth on first wheel
(*b*) More nappy cloth (e.g. Selvyt) on second wheel
(*c*) The cloths should be partly worn; if new they should be ' conditioned ' by polishing an old specimen on them
(*d*) Amount of paste on the wheels should be just sufficient to impregnate the cloth
(*e*) Cloths should never be wet, but just damp at beginning of polishing operation, and nearly dry at the end of it
(*f*) Specimen should be rotated in the opposite direction to the rotation of the wheel
(*g*) As little time as possible should be spent on the polishing wheels. Deep scratches should be removed by ' going back ' to the papers.

When diamond polishing is adopted as the standard practice, it will be found that the time factor is

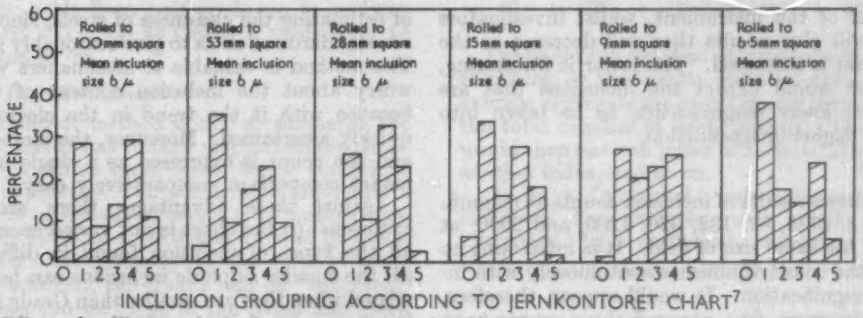

Fig. 2—Effect of rolling on inclusion-count results for globular-type oxide. Ingot size 37·2 cm (13 in.)

reduced considerably, and very good surfaces are produced even by an inexperienced operator.

Microscope

In connection with the microscope, two points are worthy of note—magnification, and field of view. The importance of magnification and field of view on the results of Fox inclusion counts is shown clearly in the following examples.

Example 1[2]

Fox inclusion counts were determined by one observer over the same fields using two microscopes. The results obtained were as follows:

Microscope	*Fox Inclusion Index*
Leitz	20
Zeiss	28

Since the same inclusions were traversed in each case, the reason for the change of instrument affecting the counts was investigated. The conditions were as follows:

Type of Microscope	*Magnification*	*True Field, mm*	*Apparent Field, mm*
Leitz	× 132	82	108
Zeiss	× 145	90	130

Let there be four investigators—*A*, *B*, *C*, and *D*—each of whom assesses the inclusion content in a particular way. The results would be briefly as follows:

Investigator A assesses the inclusion content by comparing the relative area of the inclusions to that of the steel exposed to view. This investigator will get the correct result, irrespective of magnification or field of view.

Investigator B assesses the inclusion content in terms of the apparent area of inclusions appearing on the screen. This investigator will report different counts for different microscopes. For example, with the microscopes and conditions stated above, a higher count will be obtained with the Zeiss than with the Leitz instrument.

Investigator C assesses the inclusion content in terms of the number of inclusions times their apparent lengths. This investigator will also report different counts for different microscopes. For example, using the same two microscopes and conditions as before, the count for the Zeiss instrument will be higher than the count for the Leitz.

Investigator D assesses the inclusion content in terms of the number of inclusions times their relative lengths. Using the two microscopes and conditions previously mentioned, a higher count will be obtained with the Zeiss than with the Lietz instrument.

In other words, if the apparent field is kept constant, investigators *A* and *B* will give results that are

Table I
INCLUSION COUNTS

Steel	Condition of Section	Magnification						
		× 27·5	× 83	× 132	× 250	× 520	× 1200	× 2000
1. 'Extremely clean' electric-arc basic hearth	Unetched A	5·5	—	13·0	—	7·6	7·8	6·0
	Unetched B	—	12·25	11·35	11·25	—	—	—
2. 'Clean' electric-arc basic hearth	Unetched A	20·8	—	17·2	—	14·0	10·2	8·0
	Unetched B	—	20·9	18·3	20·3	—	—	—
3. 'Commercial' electric-arc basic hearth	Unetched A	60	—	61·5	—	48	31·8	29·0
	Unetched B	—	35·5	36·2	41	—	—	—
4. 'Very clean' basic open-hearth	Unetched A	11·4	—	32·0	—	24·6	23·3	17·1
	Unetched B	—	48·5	42·0	40·0	—	—	—
5. 'Commercial' acid open-hearth	Unetched A	120	—	100·3	—	47·6	37·4	27·0
	Unetched B	—	82	71·0	61·5	—	—	—
6. 'Clean' acid open-hearth	Unetched A	102	—	79·2	—	47·0	33·4	27·0
	Unetched B	—	64·5	57·0	50	—	—	—
7. 'Clean' acid open-hearth	Unetched A	94·5	—	77·0	—	46·3	38·2	28·0
	Unetched B	—	56·0	52·5	52	—	—	—
8. 'Very clean' acid steel, high-sulphur	Unetched A	21·0	—	25·0	—	27·0	33·0	24·0
	Unetched B	—	58·0	46·0	50·7	—	—	—

independent of the instrument, whilst investigators *C* and *D* will give results that will decrease as the magnification is increased. The latter is interesting, because one would expect the inclusions that are neglected at lower magnification to be taken into account at higher magnification.

Example 2[3]

Table I shows results of inclusion counts at magnifications of × 27·5, 82, 132, 520, 1200, and 2000, at practically the same size of field. It is interesting to note that the count diminishes continuously with increase in magnification. It would appear, therefore, that the observers who assessed these counts have tended to compare linear dimensions rather than areas, and it is said[2] that it may well be that every observer is liable to take linear dimensions into account when determining the counts.

Selection of Field of View

The importance of proper selection of the fields during examination of the sample for the assessment of inclusions cannot be too strongly emphasized, because all subsequent results will be worthless if the selection is not representative. Many of the points raised in the section on "Sampling" also apply to selection of the fields. It is also important to bear in mind that the area of the sample examined is often small when compared to the total bulk of the material it represents.

Palazzi[4] claims that it is sufficient with a random sample to examine 22 fields per specimen at a magnification of × 100, which is supposed to give an error of 10%. Apart from Palazzi's work, the author is not aware of other works that give limits of precision of the inclusion-count determination introduced by sampling, i.e. selection of samples and fields of view.

REVIEW OF INCLUSION-COUNT METHODS

For the purposes of this review, the inclusion-count methods are divided into four distinct groups:

(1) Microscopic methods based on visual comparison of fields with standard charts
(2) Microscopic methods based on direct counting, and possibly measurement of inclusions
(3) Microradiographic method
(4) Magnetic methods.

Microscopic Methods Based on Visual Comparison with Standard Charts

In this group, the two most widely used methods are the Fox and Jernkontoret inclusion counts. Other methods using charts are Diergarten's inclusion count and the method reported by Walker.

Fox Inclusion Count[5]

This method was developed by Bolsover as a practical means of quantitatively estimating the inclusion content in steels. It has been, and still is, popular amongst both producers and consumers of steel in the U.K. Before it came into use, the method used for evaluating cleanness was to compare a steel with a standard material and say whether it was up to standard, dirtier than the standard, or much dirtier than the standard.

The Fox method is obviously a much better way of estimating the cleanness of steels, since conditions are standardized so as to give reasonably good results. The method is valuable to steelmakers who have to worry about the inclusion content of their steels, because with it the trend in the cleanness can be quickly ascertained. Moreover, the method is simple and the count is expressed as a single index, which makes comparison comparatively easy.

Against these advantages there are six main criticisms: (i) the chart is not varied enough to cover all the types of inclusion found in different steels; (ii) the smaller sulphide inclusions can be completely missed when they are smaller than Grade 1, no matter how numerous they are; (iii) the large, harmful inclusions can also be missed; (iv) the volume of the field is not taken into consideration; (v) inclusion counts are subject to personal judgment; and (vi) it is not always easy to obtain the size of sample stipulated (1⅝ in. dia.).

Attempts[6] have been made to use the inclusion-count rating derived by the Fox method for studying the relationship between the inclusion content and the fatigue properties of steel, but the results have been rather disappointing, because the Fox method does not give sufficient information about factors such as size, shape, distribution, and type of inclusions, some of which may have an effect on the physical properties of the steel.

The Fox inclusion count is determined by taking samples from the top, middle, and bottom of an ingot. The samples are from forged or rolled material and are 1⅝ in. dia. × ½ in. They are cut along their diameter, hardened, and prepared for micro-examination.

The section is examined from edge to edge, i.e. across the diameter of the bar, at a magnification of × 100. A complete traverse from edge to edge consists of 30 fields. To increase the reliability of the counts, two such traverses are taken; 60 fields are viewed for each specimen. Each field is compared with a standard chart and grouped according to the designation on it.

The chart consists of 12 micrographs, graded 1–4 in increasing order of severity of inclusions. Each grade has three micrographs or fields. The inclusions shown on the chart are plastic types, but when oxide types (non-plastic inclusions) are encountered, they are treated as plastic by placing them end to end.

The final inclusion-count index is derived by multiplying the number of fields in each grade by the grade number. The sum of these products is then taken as the Fox inclusion-count index. A typical record and the way of deriving the cleanness index is as follows:

Fields examined	*Grade*				
60	0	1	2	3	4
Fields or counts	18	30	10	2	—
Multiplying the fields by its corresponding grade	0	30	20	6	—
Total	0	+ 30	+ 20	+ 6	—
	= 56				
Fox Inclusion Index = 56					

In grouping the inclusion content in each field, difficulty may be experienced sometimes with grading, for example, with inclusions that are midway between two grades. In these cases, fields less than half the quantity of inclusions indicative of Grade 1 are

counted as 0, fields from half grade up to midway between 1 and 2 (i.e. 1½) as Grade 1, fields from 1½ to 2½ as 2, and so on.

Jernkontoret Inclusion Count[7]

The Jernkontoret method is not so simple as the Fox method, but it has a more comprehensive series of micrographs, which come nearer to the conditions experienced in practice. The micrographs differentiate between types of inclusion, which is of considerable help when the effect of a particular type of inclusion in relation to some property of the steel is being studied. In addition, the counts can be 'weighted,' i.e. more stress can be given to the larger and more harmful inclusions. Further, the results can be expressed in the form of frequency curves, which make comparison easy.

The main criticisms of the method are that (i) it is a comparison method and as such is subject to personal judgment, (ii) it is more difficult to use than the Fox method, and (iii) it is not always possible to obtain the size of samples stipulated.

In practice, the inclusion count is determined on suitably selected samples. The samples are cut along their longitudinal axes and the sections are hardened by heat-treatment; the cut surfaces are then prepared for microexamination. A suitable size recommended for the sample is 75 mm (2·95 in.) × 15 mm (0·59 in.). The samples may or may not be examined in the lightly etched condition.

Each field is either projected on the ground-glass screen or visually examined. A magnification of × 100 is used with an actual field of view of 0·8 mm (0·0315 in.) on the specimen, and an apparent field of view on the screen of 80 mm (3·15 in.). When using visual examination, the same magnification and field of view are employed. However, it is suggested in the method that the magnification could be increased to × 150 without much effect on the results, provided that the same field of view of 0·8 mm is still used. This is done because some observers will find the diameter on the field appears smaller than 80 mm (3·15 in.), and the increase in the magnification compensates for this optical delusion.

The counts are derived by grading the inclusions seen in each field by comparing them with the standard chart, the worst field for each type of inclusion being taken. The whole surface of the specimen can be traversed or, to save time, a definite number of fields may be chosen. The results of the counts are recorded as totals according to grade and type, e.g. Type MnS:

Fields examined	*Grade*					
	0	1	2	3	4	5
100	15	25	45	10	5	—

Inclusions of other types are recorded in a similar way. The results of the final count may be expressed in one of several ways:

(1) As shown above for each type of inclusion present in the steel.

(2) As an aggregate for each type, for example, take the count for sulphides shown above; the total number of fields in each grade is multiplied by the grade number and the products summed up, as follows:

$(15\times0)+(25\times1)+(45\times2)+(10\times3)+(5\times4)+(0\times5)$
$= (0) + (25) + (90) + (30) + (20) + (0)$
$= 165.$

The value 165 could be taken as the index for the sulphides, or the results could be expressed as an average aggregate for each type by dividing by 100, the total number of fields viewed. The sulphides would then have an index of 1·65; oxides may have another index, and so on.

(3) As a 'weighted' index for each type of inclusion; for example, each grade could be 'weighted' by a coefficient, as follows:

Grade	*Coefficient*
1	1
2	2
3	4
4	8
5	16

To obtain the 'weighted' index, the number of fields in each grade is multiplied first by the grade number, as in (2), and the product of this is then multiplied by its corresponding coefficient, as follows:

$(25\times1\times1)+(45\times2\times2)+(10\times3\times4)+(5\times4\times8)$
$= 485.$

The value 485 could be taken as the 'weighted' index, or it could be expressed as an average by dividing 485 by 100, the number of fields viewed; thus, the sulphide could have an index of 4·85; the oxides could have another index, and so on.

(4) The results could be expressed as frequency curves for each type of inclusion. In this method the number of fields of view for each grade is calculated as a percentage of the total number of fields and plotted against the corresponding grade, as shown in Fig. 3.

The results could be given according to whether the inclusions are in the thin or heavy series as designated on the chart.

(5) The results of more than one specimen could be expressed as averages of the worst fields for each type of inclusion and according to whether they were in the thin or heavy series, as shown in Table II.

The chart consists of 40 micrographs, graded 1–5 in increasing order of severity of inclusion. Each grade has four types of inclusion—*A* (sulphides), *B* (alumina), *C* (silicate), and *D* (globular oxide)—and each type is further divided into thin and heavy series.

Diergarten's Inclusion Count[8]

This method was developed specially for ball-race steels. Its main advantage is that it classifies the inclusion according to size and appearance into well defined groups. Its main disadvantage is that the grouping is rather complicated. For instance, besides the rounded and elongated shapes, there is a group for oval inclusions; the distribution patterns also include, besides the simple dot distribution, distribution patterns for double rows and in lines of dots. In addition to these disadvantages, it has been said[9] that this method may not be suitable for all types of steel because of the variations in types of inclusion that exist in different types of steel. Moreover, the results of the counts are subject to personal interpretation.

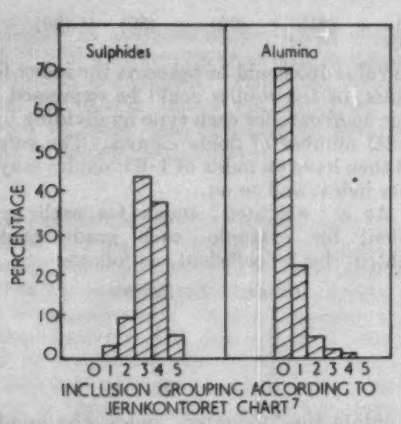

Fig. 3—Examples of inclusion counts expressed as frequency curves. Ingot size 37·2 cm (13 in.), rolled to 51 mm (~ 2 in.) square

The method consists of taking a minimum of ten samples and preparing them for micro-examination. The longitudinal faces are used. Each specimen is examined under the microscope at a magnification of × 125, and the inclusions in each field are graded according to the designation given on the chart. As in the case of the Jernkontoret method, the worst field for each type of inclusion is recorded. The inclusion count is expressed as the total number of each type of inclusion found in the various grades.

For comparison purposes, the chart consists of 50 illustrations of ' fields,' divided into (i) sulphide slags, (ii) brittle slags, and (iii) oxide slags.

The sulphide and brittle slags are each divided into five grades (1–5) with two illustrations for each grade, whilst the oxide slag is divided into six grades, each grade having the choice of five illustrations: (i) globular (O_G), (ii) lenticular (O_L), (iii) flat (O_F), (iv) double lines (O_D), and (v) multiple (O_M).

The consecutive numbers in all the columns are based on the increasing area of the inclusions.

Inclusion Count Reported by Walker[10]

One of the main advantages with this method is that large inclusions are taken into consideration. The disadvantages are (*a*) the method does not group sulphides separately but considers only two groups (one for oxides and the other for silicates), and (*b*) the results are subject to personal interpretation.

The method consists of examining six samples, $\frac{3}{4}$ in. thick, from rolled material. Samples are taken from positions corresponding to the top, middle, and bottom of the ingots. Examination consists of deep-etching the transverse sections (previously ground) in 1 : 1 hydrochloric acid at 170–180° F (76–83° C approx.). The etched surfaces are then washed in hot water, scrubbed, and dried in a blast of hot air. The sections are examined by eye in a good light for large inclusions. Inclusions that are partly attacked or do not appear to be whole are disregarded. Once the large inclusions are located, sections are cut slightly to one side of the inclusion so that after grinding and polishing it will be parallel to the direction of rolling and form part of the surface.

A magnification of × 100 is used and in each field the size, number, and appearance of each type of inclusion are noted. The fields are graded according to the designations on the chart, the final count being expressed as the total number of inclusions found in each type and grade.

The original chart consisted of 20 micrographs with numbers 1–10 assigned to each of the two types of inclusion (oxides and silicates). However, the chart has been modified since to include only 14 micrographs with numbers 2–8 inclusive for each type of inclusion.

Microscopic Methods Based on Direct Counting and Possibly Measurement of Inclusions

Many investigators have preferred to estimate the inclusion content in steels without recourse to arbitrary standards, primarily because the personal factor in these methods is reduced to as rational a basis as possible.

Several methods have been suggested for assessing the inclusion content in steel. Eleven of these are given below.

Method Proposed by Kjerrmann[11]

This method is simple and direct, but it has the following disadvantages: (i) it is tedious and time-consuming; (ii) it does not take inclusions less than 0·002 mm into account; and (iii) it gives the final count as ' number of inclusions per square millimetre ' which renders the results subject to variations due to errors in counting the very small inclusions.

In this method a sample is taken from the centre of the middle ingot of the cast. It is then forged to $\frac{1}{2}$-in. square bar, from which a specimen is taken and cut along its longitudinal axis. The cut surface is then prepared for micro-examination. The specimen is examined at a magnification of × 200, using a micrometer ocular, and all the inclusions down to 0·002 mm in each field are counted and recorded. The final inclusion count is expressed as the number of inclusions per square millimetre. Inclusions less than 0·002 mm are disregarded.

Method Proposed by Herty, Christopher, and Stewart[12]

This method was developed for studying the inclusions found in small ladle samples of steel. Its main advantage is that the inclusions are assessed in the ' as-cast ' condition, which makes their grouping easy. Another advantage with the method is that most of the inclusions will be spherical in shape, which makes their quantitative estimation easier, provided that sufficient numbers of inclusions are measured across their diameter and counted. The method has two disadvantages: first, it is tedious, and secondly, no attempt is made to differentiate between the various types of inclusion.

In this method, samples of very thin strips of steel are polished and examined under the microscope at a magnification of × 250. Each sample is surveyed from the centre to the outer edge. A micrometer ocular facilitates the measurement of the diameters of the inclusions, which are counted and grouped according to their sizes. From this result, the weight

per cent. of inclusions present in the steel is calculated, which is taken as the index of cleanness.

Method Proposed by Kinzel and Crafts[13]

Using this method, some very interesting results have been obtained in connection with the relationship between inclusion content and the mechanical properties of steel, particularly in the transverse direction. The use of photographs is interesting because it provides permanent records of the fields from which the counts could be re-assessed if necessary. Another advantage is that the inclusion content is expressed as total length, i.e. as if they were placed end to end. This method of expressing the results is weighted heavily by the large inclusions and, since there are only a few large inclusions in comparison with the small inclusions, the error in counting is not so large but is mainly due to sampling.

The disadvantages are (i) the method is tedious, (ii) inclusions smaller than 0·005 mm in size are neglected, and (iii), no attempt is made to differentiate between the various types of inclusion.

In this method transverse samples are taken from 2-in. round and square bars. They are cut along their longitudinal axes and prepared for micro-examination. The specimens are etched in a 10% aqueous solution of chromic acid to darken the sulphides and also, as Herty pointed out in the discussion on this method, any manganese silicate inclusions. Etching is done to increase the contrast between the inclusions and the steel. A plate is exposed at a magnification of × 50 for each area viewed. The developed plate is then projected so that the inclusions can be conveniently viewed. Inclusions less than 0·005 mm long are neglected. The final results are given as total length, which is taken as the index of cleanness.

Method Proposed by Epstein[14]

In this method no attempt is made to express the results of the counts in absolute terms, e.g. as the number of inclusions per square millimetre. Instead, a simple number is assigned to each specimen, which is derived by adding the ' values ' of all the inclusions found in the sample. The main disadvantage with the method is that no attempt is made to give the counts according to types of inclusion.

The method consists of taking samples from 2-in. billets corresponding to the top, middle, and bottom positions of the first, middle, and last ingots in a cast. A longitudinal section with a surface area of 0·5 in² is used. All the inclusions found in each field are measured in divisions of the micrometer ocular at a magnification of × 100 and classified into five groups:

Group	*Ocular Divisions, in. (length of inclusions)*	*Weighted Value*
Small	Up to 0·5 or 0·75	0
Medium	0·5 or 0·75–1·25	1
Large	1·25–2·0	2
Double large	2·0–3·0	4
Triple large	3·0 >	6

The inclusion-count index is derived by multiplying the total number of inclusions in each group by the ' weighted ' value. The sum of these values is then taken as the index of cleanness for each specimen.

Table II

METHOD OF PRESENTING INCLUSION-COUNT RESULTS OF SEVERAL SPECIMENS

Specimen No.	Type of Inclusion							
	A (Sulphides)		B (Alumina)		C (Silicate)		D (Globular oxide)	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
1	2·5	1	2	1·5	1	0	2	1·5
2	3	1·5	2·5	1	0	1	2·5	2
3	2	1·5	2	1	0	0	2	2
4	2·5	1·5	2·5	1·5	1	0	2·5	1
5	2·5	1	2·5	1	0	1	2	1·5
6	3	1	2	1·5	0	0	2	1
7	2·5	1·5	2·5	1	1	1	2·5	1
8	2	1	2	1·5	1	0	2	1·5
9	3	1·5	2·5	1·5	0	1	2·5	1
Average of averages	2·6	1·25	2·25	1·25	0·3	0·3	2·2	1·4

The above figures were taken from A.S.T.M. Standards, 1952

Method Proposed by Zieler[15]

In this method, the group spacings (according to the length of the inclusion) are in arithmetic progression, whilst the values or ' weights ' corresponding to each group are in geometric progression. This accentuates the influence of larger inclusions and neglects to some extent the smaller inclusions. The two main disadvantages are (i) the method is tedious, and (ii) it does not take into consideration the various types of inclusion found in steels.

The method consists of taking samples from different parts of an ingot, reducing them to suitable size by working, and selecting longitudinal samples for micro-examination. The samples are polished in the usual way and an area of 0·5 in² is examined at a magnification of × 100. The fields are then graded into the following:

Group	*Inclusion Length, mm*	*Value (or Weight)*
1	13– 26	1
2	26– 54	2
3	54–106	4
4	106–212	8

In expressing the inclusion count results, the total number of inclusions in each group is multiplied by their corresponding ' value ' and the products of these are summed up, the total being taken as the index of cleanness.

Method Proposed by Jolivet (Reported by Perrin[16]*)*

In this method the results are given as an average for each group (i.e. each size range), which makes it an attractive way of expressing the results for research purposes. The method has two disadvantages: (i) it is tedious, and (ii) it does not differentiate between the various types of inclusion found in steels.

The method consists of taking 10-mm thick transverse samples from 80-mm (3·79-in.) billets corresponding to the middle of the ingot. The samples are

cut along their longitudinal axes and prepared for micro-examination in the usual way. Two continuous strips, of the width of the microscope field are examined, extending from the outside to the centre of the sample. A magnification of × 100 is used with a field of view of 1·76 mm. The inclusions are rated in number of divisions of the ocular micrometer where one division is equal to 0·176 mm.

The inclusions are divided into groups according to their length:

Group	*Ocular Divisions*	*Actual Dimensions of Inclusions, mm*
I	4– 10	0·07–0·17
II	10– 20	0·17–0·35
III	20– 40	0·35–0·70
IV	40–100	0·70–1·76
V	> 100	> 1·76

The inclusion count is expressed as the total number (or averages in the case of more than one sample) of inclusions in each group, i.e. totals or averages for each size range.

The average of 48 casts of steel, for example, gave the following results:

Group	*Inclusion Rating*
I	8·5
II	0·85
III	<0·1
IV	—

The two best casts gave the following results:

Cast	*Group*	*Inclusion Rating*
A	I	3
	II	0·5
	III	—
	IV	—
	V	—
B	I	6
	II	—
	III	—
	IV	—
	V	—

The two worst casts gave the following results:

Cast	*Group*	*Inclusion Rating*
A	I	12
	II	2
	III	—
	IV	—
	V	—
B	I	11·5
	II	1
	III	0·5

The above figures were given by Perrin[16] for 500-kg ingots and illustrate typical inclusion counts obtained by this method.

Method Proposed by Hunter[17]

This method is one of the most comprehensive of the direct ones. Other advantages are that the total length of inclusions in a certain area of the steel is given, and also the average length of the inclusions and the length and approximate thickness of the largest inclusion. The main disadvantage is, of course, that the method is too comprehensive to be used widely industrially. Another disadvantage is that the method does not take the various types of inclusion into consideration.

The counts are determined by taking representative samples from rolled or forged material such that the surface to be examined is 1 in. square and is in the longitudinal direction to working. After preparation for micro-examination, the samples are etched to develop the necessary contrast between the inclusions and the metal. A 10% aqueous solution of chromic acid is used under normal circumstances; in some cases the desired contrast may be obtained by etching for 1 min in 1% aqueous hydrochloric acid containing 0·5% inhibitor. If the specimen is stained after etching, it is given a light polish for about 15 s on a wheel impregnated with magnesia.

The measurement and grouping of the inclusions are accomplished by projecting the field on a ground-glass screen containing a series of vertical lines $\frac{1}{10}$ in. apart over an area 5 in. deep by 3 in. wide. The magnification is standardized at × 100, so that the distance between each line of the grid represents 0·001 in. on the specimen. Three Veeder counters are used to record the following:

Number of fields examined	Counter *a*
Total lengths of inclusions in $\frac{1}{10}$ in.	Counter *b*
Number of inclusions whose lengths are measured	Counter *c*

Inclusions less than $\frac{1}{10}$ in. long (i.e. 0·001 in.) are neglected. From the data obtained from the Veeder counters the total length of inclusions over 0·001 in. long per square inch and the average length of inclusions are calculated.

To get some idea of the length and width of the largest inclusion, the specimen is traversed at a magnification of × 50, the following system being used to grade the large inclusions:

Width, in.	*Category*
< 0·0001	A
0·0001–0·0005	B
> 0·0005	C

An example of the count derived by this method is given below.

The three Veeder counters showed the following:

1st Traverse
Counter *a*: Number of fields examined 21
Counter *b*: Aggregate length of inclusions on the screen, $\frac{1}{10}$ in. 102
Counter *c*: Aggregate number of inclusions measured 86

2nd Traverse
Counter a_1: Number of fields examined 21
Counter b_1: Aggregate length of inclusions on the screen, $\frac{1}{10}$ in. 110
Counter c_1: Aggregate number of inclusions measured 90

If b and b_1 as given are within ± 10% of one another, no more counts are taken, but if the discrepancy exceeds this further traverses are made and the average is taken.

Calculation

As previously stated, the results yield the following:
(1) Length of inclusions in inches (actual) per in^2 (actual) of steel
(2) Average length of individual inclusions
(3) Length and width of largest inclusion.

To obtain (1), proceed as follows.

First find the average total length of inclusions on the screen per area:

$$\frac{b + b_1}{a + a_1} \text{ in } \frac{\text{inches}}{10}, \text{ i.e. } \frac{102 + 110}{21 + 21} = 5{\cdot}1$$

This represents 5·1/100 in. of actual inclusions in each area of 5 × 3/1000 in² of steel. Therefore, the actual length of inclusions per in² of steel is:

$$\frac{5{\cdot}1}{100} \times \frac{1000}{5 \times 3} = 5{\cdot}1 \times 0{\cdot}66 = 3{\cdot}37 \text{ in./in}^2$$

The factor of 0·66 is, of course, a constant for the conditions of measurement described, irrespective of the number of areas examined.

To obtain (2), proceed as follows:

$$\frac{b + b_1}{c + c_1} \times 10^{-3} = \frac{102 + 110}{86 + 90} \times 10^{-3} = 1{\cdot}2 \times 10^{-3}$$

To obtain (3), the specimen is surveyed at a magnification of × 50, as previously described. Assume that the largest inclusion observed is 0·012 in. in length and that its width fell within the category *B*; then for the purpose of the count this would be shown as $12B$ in.$^{-3}$

The final count is expressed as an index: 3·37/1·20/12*B*. It will be observed that for convenience the values have been rationalized.

Method Proposed by Hunter[18]

This method was developed for routine evaluation of the cleanness of steels. It is based essentially on the size of inclusions and their distribution, which makes it a simple method. Its main disadvantage is that it is difficult to obtain unanimity of opinion regarding the length of a cluster of inclusions.

In this method, a sample 1½ in. dia. by ½ in. wide, from a rolled bar, corresponding to the bottom of the last ingot of the cast, is examined. The specimen is cut along its longitudinal axis and prepared for micro-examination. The whole area of the specimen (1½ in. × ½ in.) is examined. The most satisfactory method of scanning is to proceed from one edge of the specimen to the other, and then displace the view one whole field and proceed working back towards the other edge. This is repeated until the whole of the specimen is covered.

In recording the results, the specimen can be visualized as being divided into areas equal in width to the diameter of the field of view; these are designated area 1, area 2, etc. In each of these areas, the total lengths of inclusions and/or groups of inclusions are noted and recorded in multiples of, and measured to the nearest, 0·01 in. Typical results obtained by this method are shown in Table III.

The cleanness index is given as the total count and by the maximum intensity recorded in any individual area. For example, from the above counts, it will be observed that casts *X* and *W* are reasonably clean steels; cast *Y* is next cleanest, whilst cast *Z* is the worst in the series.

Method Proposed by Hunter[19]

The basis of this test is the electropolishing of longitudinal sections of a billet so that any non-metallic inclusions will be removed and the surface brightened, thus allowing a count to be made at low magnification.

The apparatus consists of cast stainless-steel basins which act as cathodes and are connected in series. The basins are insulated by sitting them on a sheet of hard asbestos. The specimens are the anodes and the electrolyte is concentrated phosphoric acid. The specimens are held by screw clamps, which have a copper top bar. This is laid across copper busbars which carry the current, so that the specimens can be handled very rapidly. Direct current is supplied by a rectifying unit, the voltage being controlled with a transformer.

Table III

TYPICAL INCLUSION-COUNT RESULTS

Cast No.	Areas										Total
	1	2	3	4	5	6	7	8	9	10	
X	0	0	1	0	0	0	3	2	1	0	6
Y	0	5	1	3	5	2	0	4	1	0	21
Z	0	6	2	10	1	4	6	8	0	0	37
W	0	1	0	1	0	1	0	0	0	1	4

Discs 1 in. thick are cut from representative billets. The discs are halved and ground on a linisher, the finishing belt being a No. 50 grade. The final scratches are at right-angles to the direction of rolling. The ground discs are clamped and suspended so that the ground surface is just below the surface of the electrolyte (syrupy phosphoric acid). A current of 10 A is passed for 15 min. The current is switched off and the specimens are plunged rapidly into cold water to prevent staining. They are then dried and the polished face is smeared with Duraglit to prevent staining.

The Duraglit is rubbed off, leaving a bright polished surface. The face of the specimen is marked off into fields ½ in. wide and is then examined on the ground-glass screen of a projection microscope at a magnification of × 7. The unit of counting is 0·1 in., and any smaller inclusions are ignored; thus an inclusion 0·1 in. long will be counted as one, while an inclusion 0·3 in. long will be counted as three.

The results of the count are entered in a table of the type shown in Table IV. The first column gives the ingot (or billet) identification. The next six columns represent the fields into which the discs were marked. The small numbers at the top represent the lengths in 0·1-in. units in that particular field; e.g. ingot *A* in the first field showed one inclusion 0·1 in. long and two inclusions each 0·2 in. long. The penultimate column marked 'Real Length' is used for the total length of inclusions per disc; e.g. ingot *A* showed $(2 \times 1) + (2 \times 2) + (3 \times 2) = 12$.

As it is considered that long inclusions are more harmful, the influence of the longer inclusions on the count is increased by squaring their lengths. These are then totalled to give an arbitrary number known as the general rating; thus the general rating of ingot *A* is given by:

$$2 \times (1)^2 + 2 \times (2)^2 + 2 \times (3)^2 = 2 + 8 + 18 = 28.$$

It is realised that the full notation of the count is cumbersome; to obtain a figure for the cast as a whole the real lengths and general ratings of all the discs are added and divided by the total number of fields examined. Thus the real length and general rating for this cast would be respectively 0·59 and 1·85. Any cast with a general rating greater than 1·0 is considered dirty.

Table IV
RESULTS OF INCLUSION COUNTS

Ingot	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	Real Length	General Rating
A	2	2							2																12	28
B	1																								1	1
C							1						1												2	2
D	1																								1	1

In recording clusters of inclusions, and when in doubt as to the length of a cluster, the greatest estimated length is assigned to it; when an isolated inclusion occurs at the end of a group, it is only included in it when its length is greater than the distance between it and the end of the last inclusion of the group.

Method Proposed by present author

This method was originally devised for examining areas near the surface of fatigued specimens, but it has been used subsequently for assessing the inclusion content of engineering components reputed to have failed owing to non-metallic inclusions. The method has also been used satisfactorily for assessing the cleanness of casts of steel.

The main advantage with this method is that it takes into consideration such factors as the size, type, amount, and distribution of the non-metallic inclusions. Other advantages with the method are (i) the counts are independent of magnification; (ii) they are independent of standards; (iii) the sample can be of any size; (iv) the method can be used in conjunction with residue methods; (v) the sensitivity of the method can be varied to suit individual requirements; (vi) the results obtained can be used to study the relationship between the size, type, amount, and distribution of inclusions and the mechanical properties of the steel. The main disadvantage is that it is a tedious method requiring considerable experience in identification before the various types of inclusion can be grouped.

In this method, samples are taken from the bulk in such a way that it conforms to statistical sampling as described in the section on factors affecting results. For convenience of handling it is necessary to restrict the size of the samples. The actual size of the samples is not critical, provided that the area covered during microscopic examination is mentioned. In rolled or forged products, the longitudinal sections are prepared for microscopic examination. Samples are examined in the unetched condition under a microscope fitted with a micrometer ocular and polarization attachment capable of being easily detached when not in use during examination. The whole area of the specimen may be examined or the number of fields that give reproducible results may be examined. When the latter method is used for the selection of fields, it is done in a random manner so as to eliminate any personal element.

In practice, the inclusions in each field are first identified and then grouped according to their widths, in terms of the ocular divisions, as shown in Table V. The length of the longest inclusion for each type in each field is also noted and kept separately, and at the end of the count this is transferred to the record sheet (Table V). The number of inclusions according to types and sizes is recorded directly on the record sheet shown in Table V.

The results of the inclusion counts could then be expressed in one of the following ways:

(1) As totals for each type and size of inclusion (results of more than one specimen are given as averages), as shown in Table VI.

(2) As total number of inclusions of each type in each size range expressed as a percentage of the total number of fields, as shown in Table VII. These results could also be plotted as frequency curves.

(3) As a simple index for each type of inclusion; this is done by allocating each group a ' weighted ' coefficient then multiplying the totals in each group

Table V
RECORD SHEET FOR INCLUSION COUNTS

Group	Sizing (Width), mm		Type and Number of Inclusions			
	Ocular Divisions	Actual Size	Manganese Sulphide	Silicate (glass)	Silicate (plastic)	Duplex MnS/Silicate
1	0- 1	0-0·003				
2	1- 2	0·003-0·006				
3	2- 4	0·006-0·012				
4	4- 8	0·012-0·024				
5	8-16	0·024-0·048				
	Longest inclusion, mm					

Table VI

RESULTS OF INCLUSION COUNTS ACCORDING TO TYPE AND SIZE

Type of Inclusion	Group					Longest Inclusion, mm
	1	2	3	4	5	
Manganese sulphide	28	23	14	11	—	0·06
Silicate (glass)	20	24	8	2	—	0·0024
Silicate (plastic)	24	11	5	—	—	0·04
Duplex MnS/silicate	12	9	6	—	—	0·06

by its corresponding coefficient and adding up all the products in each group and dividing the sum total by the number of fields examined (in this case 100), as shown in Table VIII.

(4) The count may also be expressed as a single index derived by adding up all the totals and calculating the average in 100 fields and 1 field as follows:

In 100 fields, add the following from the ' weighted ' counts (*see* Table VIII):

$218 + 116 + 62 + 54 = 450.$

In 1 field, proceed as follows:

$450 \div 100 = 4{\cdot}50.$

This method of assessing inclusions could also be used in conjunction with residue methods, in which a sample of known volume of the material is dissolved and the inclusions and carbides in the residue are then identified, grouped, and estimated in the same way as described for micro-samples using a petrographic microscope. The results of the count can be given on a volume basis and will therefore be more quantitative. Carbides or other metallic phases in the residue can be neglected.

Method Recommended in S.A.E. Handbook[20] *and A.S.T.M. Standards*[21]

This method for assessing the inclusion content in steels is based on a combination of direct and comparison methods. Inclusions that are normally too small to be counted or are tedious to count are rated as a background (i.e. by comparison with standard charts), whilst those inclusions that are large enough are measured and counted as in the direct methods. More exacting classification of the background rating is obtained by using minus or plus signs after the background letter. In this method, samples are taken from either a 5 in. × 5 in. billet or a 2-in. dia. round bar. The samples for micro-examination are ½ in. × 1 in. in dimension, the ½ in. being parallel to the longitudinal axis of rolling. The samples are polished after hardening, ensuring that the scratches left by the last polishing operation are at right-angles to the direction of working. The samples are then examined under a microscope and each individual field of the entire polished area is projected successively on a ground-glass screen at a magnification of × 100. The ground glass is ruled with a series of parallel lines ½ in. apart. The ½-in. distance between any two parallel lines (equivalent to 0·005 in. on the specimen) is called a unit, in terms of which the lengths of inclusions are measured. From the observations on the ground-glass screen, the following three classifications are made in the sequence given:

Table VII

INCLUSION COUNTS ACCORDING TO TYPE AND SIZE EXPRESSED AS A PERCENTAGE OF THE TOTAL NUMBER OF FIELDS VIEWED

Type of Inclusion	Group				
	1	2	3	4	5
Manganese sulphide, %	37	50	19·5	14·5	—
Silicate (glass), %	37	44	14·8	3·7	—
Silicate (plastic), %	55·5	30·7	13·8	—	—
Duplex MnS/silicate, %	44·5	33·3	22·2	—	—

(Number of fields examined = 100)

Longest Inclusion—Represented by a number which corresponds to the number of units which the inclusion covers on the screen. Fractional units are not used; the nearest whole unit is recorded. The width of the longest unit may be indicated by a suffix, for example as follows:

Assume that the longest inclusion in each of two specimens is 6 units long. The difference in thickness may be denoted as 6^T, 6^H; other characteristics are denoted by 6^d, 6^{vd}, and 6^g, where,

T = thin (1 mm or less wide)
H = heavy (3 mm or over wide)
d = disconnected
vd = very disconnected
g = group.

Table VIII

INCLUSION COUNTS ACCORDING TO TYPE AND SIZE EXPRESSED AS A 'WEIGHTED' INDEX

Type of Inclusion	Groups with Corresponding Coefficients					Total	Average
	1	2	3	4	5		
	1	2	4	8	16		
Manganese sulphide	28 × 1 = 28	23 × 2 = 46	14 × 4 = 56	11 × 8 = 88	0 × 16 = 0	218	2·18
Silicate (spherical)	20 × 1 = 20	24 × 2 = 48	8 × 4 = 32	2 × 8 = 16	0 × 16 = 0	116	1·16
Silicate (plastic)	20 × 1 = 20	11 × 2 = 22	5 × 4 = 20	0 × 8 = 0	0 × 16 = 0	62	0·62
Duplex MnS/silicate	12 × 1 = 12	9 × 2 = 18	6 × 4 = 24	0 × 8 = 0	0 × 16 = 0	54	0·54

A discontinuity of not less than 1 unit along the length of an inclusion being rated arbitrarily divides it into two inclusions, the larger of which, if it is the longest in the specimen, is rated as above, and the smaller is included in the average inclusions.

Average Inclusion—The average length of all inclusions one unit and over in length, excluding the longest inclusion.

This is also designated by a number equivalent to the number of units covered by the average-length inclusion, with a suffix indicating the number of inclusions rated in arriving at the average. For example, and to continue the illustration above, the specimen rated as 6^T may have in addition two inclusions of 4 units length, one of 3 units length, and one of 1 unit length; its average rating would then be $(2 \times 4 + 3 + 1) = 12 \div 4 = 3$, and the full rating thus far would be $6^T - 3^4$.

Background—A rating designated by a letter and including all inclusions less than 1 unit long. For example, the longest and the average length of inclusions in four specimens may be 6 and 1^3 respectively, but the background may be different. The ratings for these four specimens may be $6 - 1^3 - A$; $6 - 1^3 - B$; $6 - 1^3 - C$; $6 - 1^3 - D$, where the letters A, B, C, and D refer to the classification of background.

A typical rating by this method may be $7 - 2^3 - B$; this means that the largest inclusion in the specimen is 7 units long, that all other inclusions are three in number with an average length of 2 units, and that the background rating is B as depicted in the standards provided.

Microradiographic Method

This method has not been used widely either in research or in industry, but it has certain advantages, as reported by Frith,[6] developed by Betteridge and Sharpe[22] over the other methods. One advantage is its ability to reveal the true dimension of the inclusion and not just the dimension in one plane through the inclusion. Another advantage is that the true shape and distribution of the inclusion can be readily seen from a radiographic plate. The main disadvantages are that the method cannot differentiate between the various types of inclusion and also, that the preparation of very thin samples, necessary to obtain satisfactory results, is difficult.

In this method, samples approximately 0·375 in. square by 0·002 in. thick, are used. These are prepared by cutting very thin strips about $\frac{1}{16}$ in. thick from the longitudinal plane of the material to be examined. The strip is fixed with wax to a flat metal holder and each face is in turn rubbed down on emery paper until the required thickness is obtained. An easier way of preparing the samples is to use the mechanical device described by Betteridge and Sharpe[22] for the initial part of the preparation and finish the polishing by hand before removing the specimen from the holder.

An X-ray diffraction unit is used with suitable radiation obtained from a wide range of target material. So that the radiograph obtained will be capable of sufficient magnification without loss of detail, a fine-grained emulsion is required. With steel specimens about 0·002 in. thick, an exposure of about 15 min with copper radiation, or 4 min with cobalt radiation, could be used. From the radiographs obtained in this way, inclusion counts could be made and grouped, perhaps according to shape. It is interesting to note that the size of the inclusions is larger on the radiographic plate than when it is viewed at the same magnification under a microscope. This is because the radiograph shows the whole of the inclusion (including the part inside the steel) whereas the inclusion seen under the microscope is only in one plane of the inclusion.

Magnetic Powder Methods for Counting Inclusions[20,21]

These methods for assessing the inclusion content in steels are simple, quick, and give sufficiently reliable results. Another advantage is that the cleanness in finished components can be determined, which makes it an attractive form of non-destructive test. The disadvantages are that no information about the types of inclusion present is given, and that only large inclusions can be detected.

There are three methods that are worthy of note. In one method[20] samples are cut from longitudinal quarter-section from a billet and a round specimen is turned from this sample. An arrow stamped at the end of the specimen indicates the centre of the billet and serves to locate the boundaries of the four 90° sectors. The length of the specimen may range from 6 to 10 in., depending upon the size of the billet, the longer specimen being taken from the smallest billet. Specimens may also be taken from a round billet 2 in. or more in diameter.

The specimens are rough-turned after being hardened to approximately 300 Brinell. Grinding is done transverse to the length of the specimen. The specimens are then washed to remove grease and fingermarks and magnetized by passing a heavy electric current through them for about 0·2–0·5 min. The current is varied according to the diameter of the specimen and is fixed at about 1000 A/in² of specimen diameter. A finely divided powder, usually suspended in kerosene or light oil, is applied; about 1 oz of magnetic powder to 1 gal of fluid is used. After magnetizing, care is taken not to touch or disturb the inclusion 'indications' while removing the specimen from the magnetizing apparatus. The specimen is then washed with a quick-drying solvent.

The specimen is examined under a well diffused light, when the large inclusions will be clearly visible. If inclusions of $\frac{1}{32}$ in. or smaller are of interest, a hand magnifying lens is used. The size of each inclusion appearing on the surface is recorded, the results for each of the four sectors being kept separate.

The indications representing the inclusions may be recorded by photography, by contact printing, or by drawing on a diagram. Specially prepared paper, known as imbibition paper, may also be used for recording the results. Indications could also be recorded by dipping into suitable transparent plastic; after the plastic has been removed and dried it can be mounted.

The results of the counts are expressed by weighting the inclusion for each group as follows:

Length of Inclusion, in.	*Weight*
Over $\frac{1}{16}$ to $\frac{1}{4}$	1
Over $\frac{1}{4}$ to $\frac{1}{2}$	2
Over $\frac{1}{2}$ to $\frac{3}{4}$	4
Over $\frac{3}{4}$ to 1	8
Over 1	16

From this classification the following values are obtained:

Frequency (total number of inclusions in each group/specimen)
Severity (total of weighted values for all inclusions in groups/specimen)
The averages of frequency and severity for all specimens.

In the other method,[21] specimens are 6–12 in. long and are taken from samples agreed by the consumer and the producer. The samples are either rolled or forged, hardened by heat-treatment, rough-machined, and suitably prepared, as in the first method. The samples are then cleaned and subject to magnetization by a suitable method. The results are rated according to a code, as follows:

The total number of lines per square foot
The aggregate length of all the lines per square foot
The length (inches) of the longest single line
A letter indicating the uniformity of distribution:
A = uniform distribution
B = slight tendency towards grouping
C = arranged in discernible groups
D = well defined groups of clusters.

The length of the longest line is given to the nearest 0·1 in., and the aggregate length to the nearest 1 in. To distinguish indications of exceptionally heavy nature, the letter *H* may be added to the figure giving the length of the longest line. If the average line is heavy, the letter *H* is added to the figure giving the average length. The following example will show more clearly the system of rating.

Example—The number of lines found is 42. This multiplied by the ratio 1/0·25 = 168 for the total number of lines per square foot. The total length of all the lines on the surface of the sample is 5 in. The sample had an area of 0·25 ft². The aggregate length of all the lines per square foot then would be 5 × 1/0·25 = 20. The longest line appearing on the surface is approximately 0·7 in. long, so the third number of the code would be 0·7. If this line were heavy, the third number of the code group would have *H* affixed, thus: 0·7*H*. By examination, the lines are arranged in distinct groups; the symbol *C* should therefore be used to describe the distribution of the lines on the sample. Thus, the code number or rating by this method for the sample would be 168 - 20 - 0·7*H* - *C*.

Permanent records may be made of the indications by any of the techniques mentioned in the first method.

In another method,[23] a length of billet from the middle of the middle ingot is used which is step machined, an eighth, a sixteenth, etc. A fine emery finish is required on the stepped portions.

The reason for the dimensions used is that experience has shown that the layer of metal just below the skin usually has the heaviest concentration of non-metallic inclusions, and that machined components usually have a large proportion of the machined surfaces within the dimensional limits of the test.

The machined test-piece is magnetically crack-detected using a minimum current of 900 A, the high current increasing the sensitivity. The lengths of all inclusions over 0·1 in. long are measured and added together. The total area examined is measured by measuring the total periphery of the three steps and multiplying by two. As the area of the test-piece varies according to its original diameter, the results are expressed as length of inclusions per 100 in²: i.e.

$$\left(\frac{\text{Total length of inclusion}}{\text{Total area of steps}} \times 100\right)$$

The results are rated as follows:

Length of Inclusion Indication	*Rating*
0– 1	Very good
1– 5	Good
5– 10	Fair
7–110	Reject

Where a reject rating is obtained, additional samples are tested.

DISCUSSION OF METHODS FOR ASSESSING INCLUSIONS IN STEEL

The first general comment to be made in connection with the inclusion-count methods is that none of them is capable of providing all the information necessary in an ideal count for determining the relationship between inclusions and the physical properties of steel. It is clear from this review that there is still much to be done before a really scientific method can be developed. It is, indeed, difficult to foresee much development in this field for some time until it is possible to obtain more information about the importance such factors as type, size, shape, distribution, and amount of inclusions have in relation to the mechanical properties of the steel. Any attempt to develop an ideal inclusion-count method at this stage is unsound in conception and, perhaps, impossible of fulfilment.

The comparison methods have given a good indication of the cleanness of steels and will no doubt continue to be of great help to steelmakers controlling quality. As far as research is concerned, these comparison methods, especially the Fox inclusion-count method, do not give sufficiently reliable information. They are subject to personal interpretation, which makes comparison of results difficult.

These deficiencies are overcome to some extent in the direct methods, which vary greatly in complexity; they are capable of yielding much of the information necessary in establishing the relationship between inclusions and the mechanical properties of the steel. However, as with the comparison methods, the volume of steel represented is not taken into account. The main disadvantage with these direct methods is that they are tedious and time-consuming and are, therefore, quite unsuited for industrial use; for research purposes, however, some of them have yielded valuable results.

The microradiographic method is capable of yielding interesting information. It can give the number, shape, and size of the inclusions present in a certain volume of steel. However, the laborious preparations necessary for successful results to be obtained, and also the fact that the method is not capable of

differentiating between types of inclusion, are factors likely to hinder the wide use of this method.

In contrast to the microradiographic method, magnetic methods for determining inclusion counts are widely used industrially. The methods are simple, quick, and give sufficiently reliable information about large inclusions to enable steels to be classified into various groups of cleanness. Their main disadvantage is that they do not differentiate between types of inclusion; also, small inclusions cannot be detected by these methods.

RECOMMENDATIONS

It is clear from this review that a more scientific method for assessing inclusions is necessary. Although it may not be possible to devise a really scientific method with the present state of knowledge of the true significance of inclusions in relation to the mechanical properties of steel, many aspects of the inclusion-count methods could be developed scientifically, which would make existing methods easier to apply and the results obtained more reliable. For example, improvements can be effected in the following:

(1) Method of counting

(2) Method of choosing the fields of view

(3) Method of sampling.

The method of counting could be speeded up by using more scientific techniques. For example, point counters are now available that can be fitted on to an ordinary microscope, with the aid of which fields can be chosen much more efficiently. They choose the fields automatically when a button is pressed and also have means for automatically recording the necessary information required, such as type of inclusion, etc. The possibility of using a flying-spot microscope for deriving a count could also be studied.

Work could also be undertaken on improving sampling techniques. The current practice is to examine the surface of polished samples of steel under a microscope and then make an estimate of the non-metallic matter present. This is not really satisfactory because the counts can be made only in two dimensions; moreover, it is more difficult to differentiate between the various types of inclusion, owing to their being embedded in the steel matrix. Counts in three dimensions would be more satisfactory, as this would take the volume of steel into consideration and at the same time make identification easier. It is recommended that samples of inclusions obtained by chemical separation methods or very thin samples should be used for estimating microscopically the non-metallic content in steel. A method that dissolves the steel and leaves the inclusions *in situ* would be preferable. Methods devised on these lines would overcome many of the disadvantages of the previous methods and be capable of giving quantitative results. Undissolved carbides in the residue can be either counted or neglected.

Other aspects of inclusion counting worthy of careful study are the following:

(1) The minimum number of samples and fields to be examined in order to obtain reproducible results. At present there is much confusion as to what constitutes good practice.

(2) The distribution of inclusions in an ingot from a statistical point of view.

Systematic work on these lines should be of considerable interest to both consumers and producers of steel.

Acknowledgments

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Development of Methods for Isolating Structural Constituents in Steels

By W. Koch and H. Sundermann

SYNOPSIS

In conjunction with earlier work this paper surveys the present position of methods for the electrolytic isolation of the various structural constituents in steel. The most important items of apparatus, the electrolytes used, and the sources of error are described. The electrolytic dissolution of steel specimens can take place in three distinct potential regions according to the electrolyte selected, and follows a correspondingly different pattern. Dissolution can be classified as ferrous iron active, ferrous iron partly passive, and ferric iron active. The mixture of different structural constituents present after isolation is further separated in many cases, various chemical and physical processes serving for this purpose. A recently developed magnetic separation method is described in more detail. Isolation methods have been incorporated to an increasing extent in recent years in metallurgical and metallographic research work. 1588

WITH THE INCREASINGLY SEVERE DEMANDS made on steel quality today, it becomes more essential to determine the relationships which exist between structural composition and physical and chemical properties. In this connection phases which exist in the metals in small amounts and in a finely distributed condition are often a determining factor.

To examine these phases, it has up to the present been necessary to free or 'isolate' them from the metal to be able to carry out microanalytical, structural, microscopic, and electron-microscopic investigations. This research technique is known in Germany as metallographic analysis; its development was surveyed in 1949 by Klinger and Koch.[1] Since then, however, the technique has been further improved, and these newer developments will be briefly reviewed in the present paper.

DEVELOPMENT OF A NEW ISOLATING APPARATUS

When dissolving steels in the equipment described earlier by Klinger and Koch,[1] a non-uniform attack was obtained on the originally cylindrical test-piece, as can be seen from Fig. 1. This shows that the current density associated with the state of polarization and solution potential on the steel sample, and conditioned by the asymmetrical arrangement of anode and cathode, is not the same at all points on the surface of the test-piece when using this apparatus.

Cases occur repeatedly in which even small potential differences have an unfavourable influence on the isolation results. Hence an apparatus was first developed by Koch and Sundermann[2] in which anode and cathode are so arranged that, at least in the macroscopic region, the potential is equal over the whole of the dissolving test surface. This equipment is shown in Fig. 2.

As electrolytes containing fluoride are also used, it is made of a transparent plastic. The cathode region surrounds the anode region, the design being similar to that developed by Heiskanen.[3] The zones are separated by a cylindrical diaphragm, fitted with a plexiglass window. The anode and cathode regions are kept in a protective atmosphere of nitrogen, argon, or carbon dioxide.

The test-piece is cylindrical, and its ends are covered with paraffin wax, so that only the generated surface is dissolved. The cathode consists of three gauze electrodes of platinum or gold–platinum, the spatial arrangement of which ensures an almost cylindro-symmetrical potential distribution. The anode space, which is connected below with the storage and receiving vessel, holds 2 l. of electrolyte. The renewal of electrolyte, accomplished in the earlier model by continuous supply and withdrawal of electrolyte, is ensured in the new instrument as follows. The high-density used electrolyte, containing iron, is collected at the lower end of the specimen, and by means of a funnel and delivery tube forms a layer below the still-unused electrolyte. A clearly delineated phase boundary is formed between the layers. In this way fresh electrolyte corresponding exactly to the required consumption is supplied continuously.

The diameter of the delivery tube is adjusted according to the applied current strength; the funnel can be changed for different test-pieces. With the correct dimensions, about 0·5 l. of electrolyte is consumed for the solution of 1 g of iron. Isolated material falling from the specimen is collected in a receiver placed inside the funnel assembly below the sample, while isolated particles carried down with the used electrolyte collect at the bottom of a beaker, which seals off the base of the apparatus. By means of an outlet in this beaker, part of the electrolyte can be run off, and by this means a sample of the metal-enriched electrolytic solution can be taken during electrolysis, and the composition of the dissolved portion determined. It is also possible to add fresh electrolyte during electrolysis.

To facilitate cleaning, the equipment can be taken apart, the diaphragm, upper and lower parts of the instrument, beaker, and cover (to which the cathode is firmly secured) being detachable.

By the use of this apparatus the desired statistically uniform surface attack is obtained. The mean and true current densities now correspond, leading to homogeneous solution at a uniform potential. Because in the earlier form of the apparatus it was necessary to regulate the solution conditions according to the maximum permissible current density or potential, and since in the new apparatus it is uniform over the

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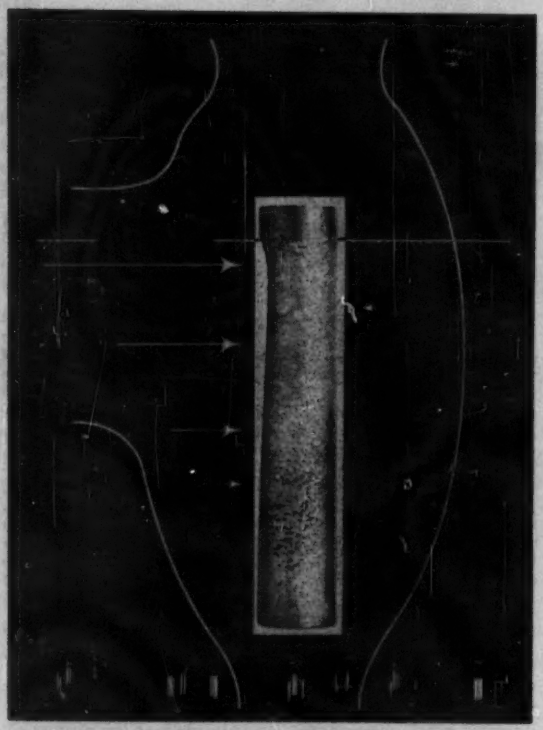


Fig. 1—Non-uniform attack on the original cylindrical specimen in the apparatus of Klinger and Koch

whole surface, the average current density can be set to about three times its former value. This shortens the time necessary for isolation and reduces chemical attack by electrolyte on the free isolated material.

Using this apparatus, the sample is in all cases only partly dissolved, the weight consumed being determined by difference. In investigations on cast iron, however, it is often desirable to dissolve the specimen completely. For this purpose an apparatus was developed by Wittmoser and Gras[4] in which two flat electrodes were placed parallel to each other. This equipment can give good service in the examination of sheet samples.

UNDESIRABLE REACTIONS DURING ELECTROLYSIS

During the isolation process a number of undesirable reactions, which must be counteracted, take place at the surface of the specimen on the solution front or in the electrolyte. The most important are the precipitation of hydroxides and the attack on the isolated constituents by the electrolytes used.

Prevention of Hydroxide Formation

If a perfectly neutral solution of potassium bromide, freed from dissolved oxygen, is introduced to the anode and cathode chambers of the isolation apparatus, and iron is then dissolved anodically in this electrolyte, the separation of hydrogen in the cathode zone is accompanied by an equivalent evolution of OH ions. Unless precautions are taken, the latter are transported by the current into the anode zone, and can give rise to hydroxide formation. In order to prevent the contribution of OH ions to the conveyance of current, and hence their transfer through the diaphragm to the anode space, the electrolyte must be kept slightly acid in the cathode zone. This can be done most simply in the new apparatus by adding and buffering an excess of acid equivalent to the estimated A-h value before beginning electrolysis.

Even when this influence has been eliminated, certain pH changes take place in the anode zone. The iron goes into solution as Fe^{++}ion, and undissociated $Fe(OH)_2$ is formed within the compass of the solubility product, and the pH value falls slightly as shown in Fig. 3 for various initial pH values. It also follows from the diagram in which the limit of ferrous hydroxide formation is plotted, that no precipitation of $Fe(OH)_2$ occurs from this cause.

During anodic solution an iron-rich zone is built up very rapidly at the surface of the sample, having a quite specific iron content. In this way a specific pH value is obtained with constant solution of iron and a continuous supply of fresh electrolyte.

In practice, when dissolving unalloyed steels in alkali halide solutions, it is necessary carefully to remove the oxygen dissolved in the electrolyte. If some oxygen remains in solution, the divalent iron is oxidized and ferric hydroxide is precipitated from the almost neutral solution.

If the steel to be dissolved contains several percent of chromium, small amounts of dissolved oxygen no longer lead to the formation of ferric hydrate. This is brought about by an electrode reaction of Cr, which leads to a still more pronounced reduction in the pH value. Chromic chloride normally exists in aqueous solution as the green aquo-system $Cr(H_2O)_4Cl_2.Cl$.

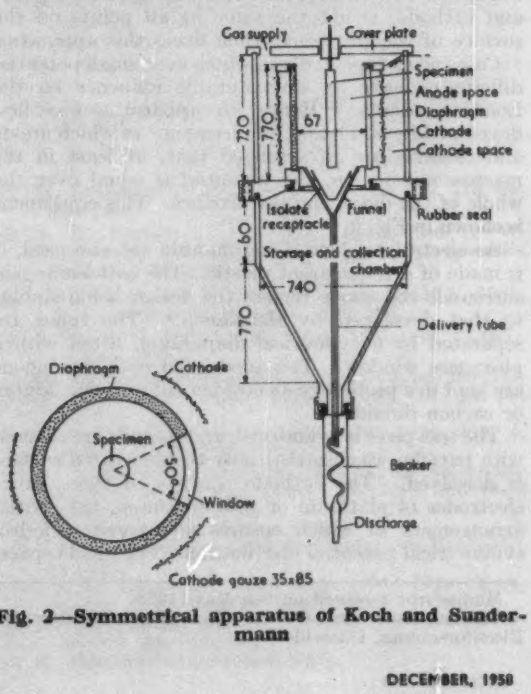


Fig. 2—Symmetrical apparatus of Koch and Sundermann

After long standing or on boiling such a solution, this complex changes into a more stable violet form. This process is associated with a diminishing pH value, indicating that OH ions are also combined in this complex. The violet form, which is also generally considered to be an aquo-system, must therefore be assigned the general formula $Cr(H_2O)_x(OH)_yCl_z$. H_{x+y-3}; with $x + y - z = 6$. On electrolysis the violet form appears immediately.

The authors suppose that the Cr ion exists in the first place as an adsorption atom without a hydrate sheath; in this way the direct formation of the violet complex is made possible by the diminished activation threshold. For the electrolytic solution of chromium-alloy steels therefore, a pure 3% solution of potassium bromide has proved to be the most suitable electrolyte in many cases.

Prevention of Hydroxide Precipitation by the Addition of Citrate

In order to prevent with certainty the formation of ferric hydroxide in unalloyed steels, electrolytes containing citrate are used, in which the iron is complexed. The initial pH value of the electrolyte can then be varied, by means of NaOH, between 6 and 9 according to the amount of citrate added. This is particularly important for the isolation of acid-sensitive sulphides.[5] If an electrolyte containing citrate is used for dissolving Cr steels, then chromium hydroxide is readily precipitated from steels with higher Cr contents, as Cr, unlike iron, is not bound by citrate as a stable complex. In order to suppress this hydroxide formation, and overcome the passivity of Cr steels, electrolysis was carried out with square-wave a.c., following a recommendation by Klinger and Koch.[1] By this

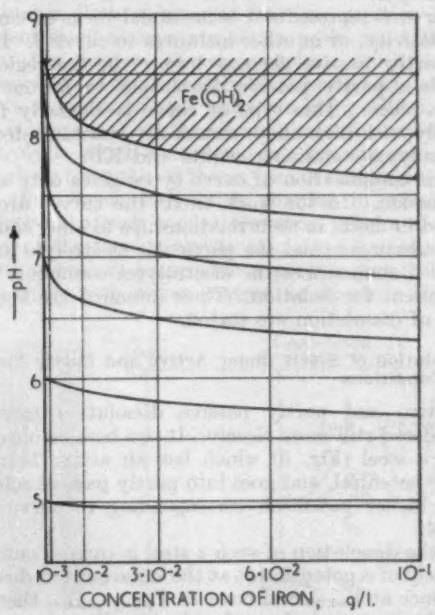


Fig. 3—pH variation in the electrolyte with increasing iron dissolution as a function of initial pH value

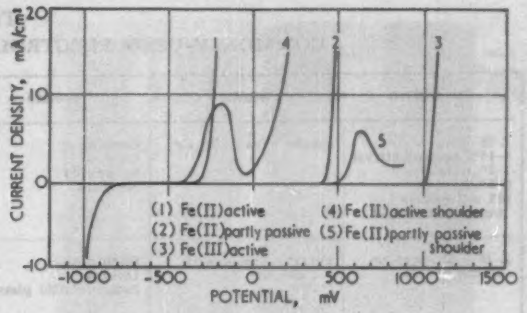


Fig. 4—Current density/potential curves

means the precipitation of chromium hydroxide at the electrode could be prevented in many cases. This is not, however, solely the result of activation, but was also related to the displacement of the pH value, as more recent investigations established. Electrolytic isolation therefore can be carried out in almost all cases by the use of d.c., if the pH value is suitably adjusted.

Influence of Electrode Potential in Anodic Solution

As steels have widely variable properties, depending on the alloying constituents present, it is appropriate to classify them into four groups for the purpose of the following discussion.

(i) Dead mild steels, rimming and killed, with up to 0·1%C, which are unalloyed apart from certain amounts of Si and Mn

(ii) Structural steels containing about 0·1–0·6%C, either unalloyed or with a maximum of 2% Cr, Ni, Mo, V, and W

(iii) Tool steels with carbon contents greater than 0·6%, to some extent alloyed with higher concentrations of Mn, Ni, Co, Mo, V, and W, but with Cr content not exceeding 6%

(iv) Ferritic and austenitic chemically resistant steels with Cr contents over 12% and a series of further alloying metals.

There are no sharp dividing lines between the above groups. Various steels not comprised in the grouping, for example steels with specific physical properties, can be classified into one of the above groups, according to their electrochemical behaviour. This also applies to cast-iron alloys.

Current Density/Potential Curves of Various Steels

An explanation of the electrochemical principles underlying isolation was put forward by Koch,[6] and by Koch, Ramsauer, and Stackelberg.[7] More recently the electrochemical behaviour of steels in the separate groups was investigated by Koch and Sundermann[8] in various structural conditions with the different electrolytes used for isolation, and with the help of a potentiostat described by Koch and Lüdering.[9] Current density/potential curves were plotted; these proved that dissolution proceeded according to the existing electrode system, either actively or with partial passivation. By ' partial passivation ' should be understood here a dissolution in which parts of the surface remain unattacked and solution occurs only at certain ' active locations.' The various types of dissolution correspond to different positions of the current density/potential curves (Fig. 4).

Table I

COMMONLY-USED ELECTROLYTES AND THEIR APPLICATIONS

Electrolyte	Steels	Isolate	pH	Type of Dissolution	Remarks	Reference
Z–B 5–15% sodium citrate 1·2% KBr 0·6% KI pH adjustable between 6 and 9	Steels with < 7% Cr	Carbides Oxides Sulphides Nitrides	9	Ferrous iron, active; ferrous iron, partly passive	Polarisation increases with increasing chromium and carbon contents	1
Z–B + 2% ferrous citrate	Ferritic steels with < 20% Cr	Carbides Oxides Intermetallic phases	5	Ferrous iron, partly passive with increased active positions	...	2, 8
5% sodium citrate + 5% sodium acetate + 1% KCNS + 1% ascorbic acid	High-alloy steels	Carbides Oxides	...	Ferrous iron, active–ferrous iron, partly passive with Cr contents of > 12%	...	10
5% sodium citrate + 5% zinc sulphate	Zn–Fe alloys	Iron–zinc compounds	...	...	...	31
3% KBr	Steels with Cr contents < 2% and for corrosion-resistant ferritic steels	Carbides Oxides Intermetallic phases	4–5	Up to 7% Cr ferrous iron, active; above 7% Cr ferrous iron, partly passive	With steels containing < 2% Cr, O_2 must previously be removed completely from the electrolyte	2, 6
3% KCl	High-alloy austenitic steels	Carbides Oxides Intermetallic phases	4–5	Ferrous iron, partly passive; ferric iron, active	Applicability to be tested in each individual case	2, 6
3% $(NH_4)_2F_2$	Corrosion-resistant steels	At present only for isolation of oxides	...	Ferric iron, active	Double fluorides are formed readily	
1% HCl in alcohol	Alloy steels	Acid-resistant carbides	1–2	Ferrous iron, active	Isolate to be tested for resistance to acid attack	3

Curve 1 is an example of 'active ferrous dissolution.' From the steady potential, which lies at about 400 mV measured against the standard hydrogen electrode, the current density rises proportionately to increasing potential, and leads over the whole range to an even solution of the electrode over the whole of its surface. This type of curve is found in group (i) (the mild steels), and also in the low-alloy structural and tool steels of groups (ii) and (iii). It occurs both in pure KBr electrolytes and those to which citrate has been added.[1] The latter contain KBr and KI, and will henceforth be referred to as 'Z–B electrolyte.'

The shape of curve 2 is characteristic of 'partly passive ferrous dissolution' as it occurs in KBr and Z–B electrolytes with many tool and structural steels of groups (ii) and (iii), and also in steels with more than 5% Cr of group (iv). Steels of group (iv) remain practically passive up to potentials between 0 and 400 mV. Then a divalent dissolution begins at certain points, causing pitting.

Transitional curves 4 with an 'active ferrous hump' often exist between curves 1 and 2. These are very often found in groups (ii) and (iii) during dissolution in Z–B electrolytes. The current density/potential curves in these steels are often closely related to the heat-treatment undergone by the sample.

Curve 3 is obtained with 'active ferric dissolution.' Up to about 1000 mV the behaviour of the electrodes is in general passive. Then the steel begins to dissolve over the whole of its surface to trivalent iron. This type of curve occurs particularly in the group of high-alloy, chemically resistant steels when dissolving in ammonium fluoride (and in some cases KCl) electrolyte.

Curve 5 represents a transitional form of curve 2 to passivity, or in other instances to curve 3. It has a 'partly passive ferrous hump' in the region of which a partly passive dissolution to ferrous iron takes place. This type of curve is similarly found mainly with high-alloy, chemically resistant steels in electrolytes containing citrate and KBr.

This classification of curve types gives only a first impression. In the work cited[8] the curves are discussed in detail in their relationships to alloy content, heat-treatment, and the particular electrolyte in use. Table I summarizes the electrolytes commonly used at present for isolation. Their intended use and the type of dissolution are stated.

Dissolution of Steels under Active and Partly Passive Conditions

Active and partly passive dissolution must be considered still more closely. It can best be observed with a steel (Fig. 5) which has an active hump at a low potential, and goes into partly passive solution at a higher potential, corresponding to curve 4 in Fig. 4.

If the dissolution of such a steel is carried out with the help of a potentiostat at the same current density, but once at V_{active} and once at $V_{partly\ passive}$, then the sample is attacked uniformly at V_a, as can be seen in Fig. 5*a*, while the attack at V_{pp} gives rise to

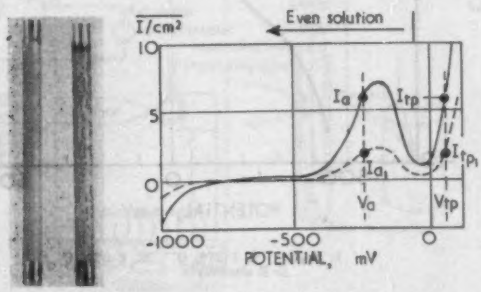
pitting (Fig. 5*b*). As the points of attack constitute only a small fraction of the total surface of the sample, the effective current density at these positions, as a ratio of the total surface area F_g to the area attacked F_a, must be higher than the reading to be derived from the diagram.

Such a pitting action occurs only in association with passivation, irrespective of whether the material was inherently passive, as for example in the chemically resistant stainless steels, or in this condition from polarization due to the effect of the current. The mechanism of dissolution associated with pitting was investigated more thoroughly by Koch and Sundermann.[9]

The process of forming centres is checked only as long as the potential V_{pp} necessary for the breakthrough is exceeded. Once formed, the active surfaces remain active. The individual centres can still become somewhat enlarged, however, and the potential can slowly fall still further. The dissolution process evidently takes place more easily than the new passivation. It is important for the process of isolation that *one* limiting potential exists for *one* electrode system, below which no further active locations can be formed. With partly passive ferrous dissolution, therefore, there is a form of dissolution which proceeds at a constant potential, and hence a potentiostatic solution in which the potential adjusts itself automatically. These conditions lead on the whole to very constant and, given a correct potential level, to favourable isolation conditions.

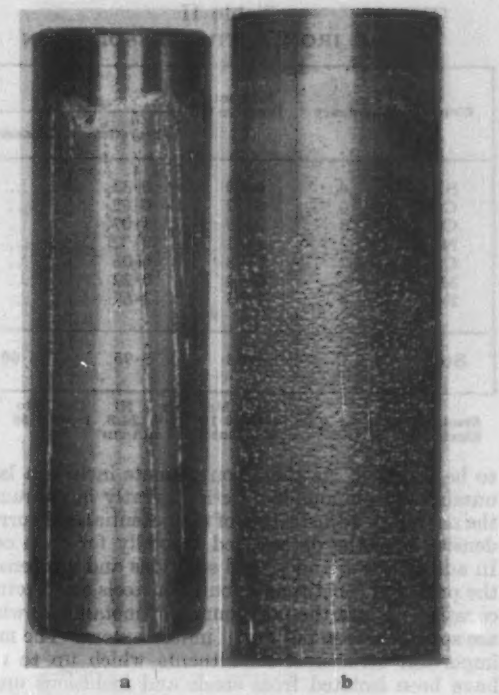
The position of the limiting potential in partly passive dissolution can be influenced here only by the electrolyte. A marked activation of the sample surface of passive steels takes place, for instance, along a layer containing ferrous citrate moving downwards (Fig. 6*a*). According to the mechanism outlined in Fig. 5, the iron in these steels goes first into solution in the divalent state at separate active positions, and then forms the ferrous citrate complex, which in the presence of oxygen is readily transformed into a ferric citrate complex of still unknown composition.

It is supposed that the ferrous citrate formed during electrolysis, which sinks down as a layer at the anode, acts along this path on the oxygen of the passive layer and thus forms the active channel in which the electrolytic attack moves forward. The activating effect of the ferrous citrate can also be used in the isolation process to provide a greater proportion of the surface with active centres, as shown in Fig. 6*b*.



(*a*) Active (*b*) Partly passive

Fig. 5—Active and partly passive dissolution



a Active channels of striae sinking longitudinally
b Activation of the passive layer by addition of Fe_2Cl_6
$Fe_2Cit. + O_2 \rightarrow Fe_2Cit.$
Steel composition, %: 0·008 C, 0·23 S, 0·40 Mn, 17·8 Cr, 0·56 Ti

Fig. 6—Activation of the surfaces of specimens of passive steels

In this way activation of a larger part of the sample surface and a lowering of the limiting potential are achieved. By adding reducing agents Piper *et al.*[10] have also obtained an extensive activation, at a diminished limiting potential, with stainless steels.

Active dissolution covering the whole of the area of an initially passive surface is also achieved in electrolytes containing fluoride,[8] i.e. ammonium fluoride. In this case dissolution proceeds at a substantially higher potential, with the formation of trivalent iron and hexavalent chromium, as shown in Table II. Owing to the mainly low solubility products of the bivalent and trivalent double fluorides these electrolytes must be more highly diluted and used at a diminished conductivity. They are at present being tested, hence their application is still limited.

The formation of active centres in electrolytic isolation can often be significantly increased by immersing the specimen for a short time in a warm solution of ammonium fluoride immediately before electrolytic dissolution. In this way passivation is also affected, and to some extent counterbalanced. A larger number of active positions is obtained, together with dissolution at a low potential.

The Electrochemical Conditions with Respect to the Isolate

In electrolytic isolation particular attention must be paid to the electrochemical behaviour of the phases

Table II
FERRIC IRON ACTIVE DISSOLUTION

Element	Valency	Amount Dissolved, g	A-h	
			Theoretical	Measured
Si	4	0·09	0·33	...
Cr	6	0·22	0·68	...
Cr	3	0·69	1·07	...
Ni	2	1·01	0·92	...
Cu	2	0·08	0·06	...
Mo	6	0·14	0·22	...
Fe	3	1·85	2·67	...
Steel	...	4·08	5·95	6·00

	C	Si	Mn	Cr	Ni	Cu	Mo	Fe
Steel analysis, %:	0·66	2·11	0·18	22·4	24·8	1·84	3·50	45

Electrolyte: 3% KCl; current density 10 mA/cm²

to be isolated. As these constituents include a large number of compounds differing greatly in character, the necessary adjustments of the potential and current density must be determined specially for each case. In addition to α and γ solid solutions and martensite, the principal constituents found in steels as structural constituents are the compounds of metalloids, which are soluble in iron only to a limited extent. The most important structural constituents which up to now have been isolated from steels and inclusions under the conditions outlined and analysed are as follows:

Structural Components Isolated

Carbides: Fe_3C TiC VC WC $Me_{23}C_6$ $Cr_{23}C_6$ Me_6C Cr_7C_3 Mo_2C (Nb–Ta)C

Oxides: Wüstite Fe_2O_4 MnO–SiO_2 SiO_2 Al_2O_3 TiO_2 Cr_2O_3 Spinels Silicates

Sulphides: MnS FeS

Phosphides: Fe_3P Fe_2P

Nitrides: AlN TiN

Others: α-iron γ-iron Graphite σ-phase Cu α-titanium

In so far as these phases consist of non-conductors, they remain practically untouched by the electrolytic processes associated with isolation. Substances of this type, to which, for example, most oxides belong, can be isolated if solutions are used as electrolytes to which these substances possess sufficient chemical resistance in the required solution periods.

For electrically conducting compounds, which include practically all carbides, their chemical resistance in the solutions used is only one requirement for isolation. It is also necessary that they should not be dissolved or decomposed electrolytically.

In assessing the quality of purely chemical resistance it must be taken into account that the solvent is modified by taking up iron and other metal ions during the isolation process, and the pH value in the neighbourhood of the electrodes can differ from that of the electrolyte as a whole; moreover, the particles often exist in the structure in greatly varying sizes. The experimental determination of their resistance is therefore carried out, when possible, on isolated structural particles. The solubility properties of synthetically produced compounds often differ considerably, however, from the structural constituents actually present in the steel.

The resistance to electrochemical attack can only be reliably determined if the current density/potential curves not only of the steels, but also of the various structural constituents which are conductors or semi-conductors, are known for the electrolytes used for isolation. The establishment of these data is at present the object of further investigations. Figure 7 gives an example of the current density/potential curve 1 of an isolated pure iron carbide in Z–B electrolyte.

The preparation of this type of curve is associated with experimental difficulties. In the first place it is necessary to isolate in a pure state a sufficiently large amount of the structural constituent; in addition, it must be possible to make an electrode suitable for measurement from the powder. The curve in the diagram was obtained with isolated cementite, from which a solid electrode was produced under high pressure.

It will be seen from the diagram that the steady potential of this cementite lies at — 170 mV E_h. At lower potentials a relatively heavy current flows at first, without any evolution of hydrogen being observed. This current decreases with time. With the authors' electrode, however, the measurement can

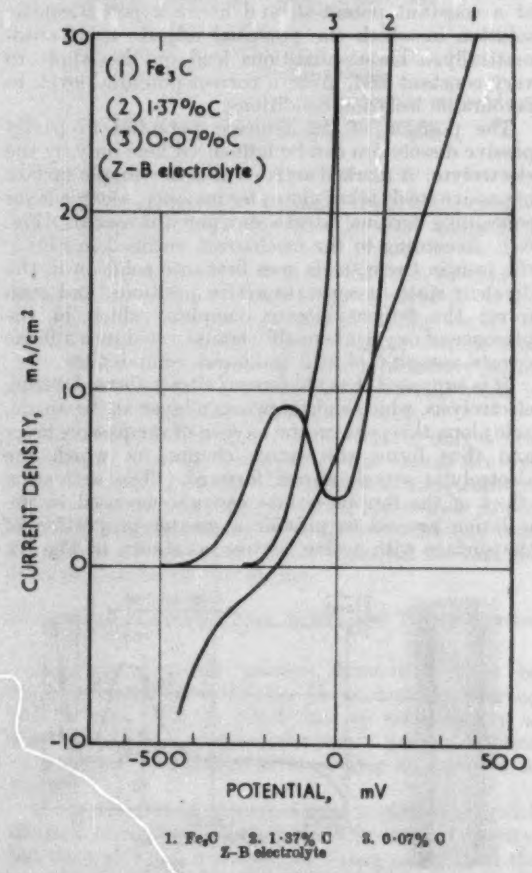


Fig. 7—Current density/potential curves of cementite compared with those of unalloyed steels

be carried out in this region for only a short time, as the compressed specimen disintegrates on maintaining it for long periods at potentials below the steady potential. It is assumed that the breakdown of the sample is because it takes up hydrogen. When the steady potential is exceeded the iron in the cementite is liberated, and free, amorphous carbon remains. The electrode goes actively into solution and Fe^{++} ions are formed. The complete process corresponds to the following equation:

$$Fe_3C - 6\theta \rightarrow 3Fe^{++} + C$$

The current density/potential curve for cementite is compared in Fig. 7 with two similar curves (2 and 3) derived from ferritic-pearlitic steels, in which a cementite existed of practically the same composition. Curve 2 is that of the steel from which the cementite used for plotting the curve was isolated. This curve, corresponding to the earlier analysis of Fig. 4 curve 4, shows an active hump with a final partly passive dissolution. It can now be readily derived from a comparison of the steel and cementite curves that a maximum current density of 9 mA/cm² may be used in this steel for isolating the cementite in the active range after 5 min electrolysis, if the steady potential of the cementite (— 170 mV) is not to be exceeded. The carbide begins to decompose only after this potential or current density is exceeded.

From the current density/potential curves plotted for other unalloyed steels it can be inferred that the conditions of isolation can alter considerably from case to case. If a current density/potential curve of a soft iron[3] is compared with that of the carbide, it is clear that only a current density not exceeding 2 mA/cm² is permissible if the carbide is to be isolated completely unattacked.

As most of the steel current density/potential curves rise more steeply to higher potentials than those plotted for carbides, isolation also takes place at current densities above the steady potential of the cementite. However, the cementite isolated in these circumstances has been attacked, which can be recognized, amongst other indications, by the fact that the isolate, to a degree depending on the extent of decomposition, contains more carbon than is anticipated from the stoichiometric composition of the carbide.

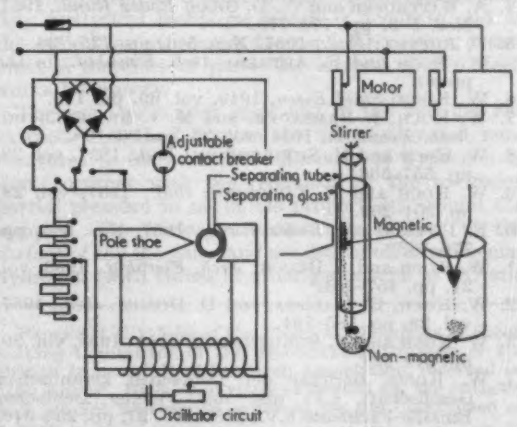


Fig. 8—Diagram of magnetic separation apparatus

	(a) Strongly magnetic		(b) Non-magnetic		
Steel		0·03	1·64		
Balance		0·024	0·53	2·65	
Isolate	3·60	C	P	Fe	X-ray analysis
Strongly magnetic	3·37	0·56	14·2	77	Fe_3P
Weakly magnetic	0·08	1·8	12·9	61	Fe_3P
Non-magnetic	0·15	2·4	19·1	67	Fe_3P

Fig. 9—Magnetic separation of Fe_3P and Fe_3P

It follows from these investigations that narrow ranges of potential must be maintained to control the dissolution process and ensure a high degree of selective separation. This is achieved with the greatest certainty in active dissolution if the potential is held electronically at a constant value by means of a potentiostat.

NEW METHODS OF SEPARATION

With the help of isolation it is possible today in most cases to obtain the structural constituent to be examined in a free state. The isolated constituents, termed 'isolates' for the sake of brevity, are then available for further investigation. As a rule, however, they consist of a mixture of several phases. To be able to draw conclusions as to the proportions and chemical compositions of the separate constituents, they must often be further separated. In addition to the isolation procedures, the methods of separation developed for this purpose are of great importance for complete investigation.

One of the most important of these methods, the so-called chlorine vacuum group separation, by the aid of which oxide is separated from the isolate, has already been described in an earlier paper.[1] Further

reference will be made in the present work only to density methods of separation,[11] separation with the manipulator[12] and by surface-active media.[4, 5] Special importance is attached at the present day to magnetic separation, which has already been used in several applications for isolation.[4] The method can be made highly selective. Starting from the concept that the mechanically retained non-magnetic portion of the isolate can be released from interlocking with the magnetic constituent by rotating in a magnetic field, or in a pulsating magnetic field, an apparatus was developed by Koch and Sundermann,[13] a diagram of which is reproduced in Fig. 8.

Construction and Operation of Magnetic Separation Apparatus

Specially formed pole shoes 1 ensure a powerful field with high gradients. An adjustable contact-breaker 2 provides for periodical switching off and on of the current supply. During the 'off' period, however, the remanence of the pole shoes and the residual magnetism of the isolate would cause the magnetic particles to remain strongly attracted. To diminish residual magnetism and remanence, the field coil circuit was connected to an oscillating circuit 3. With rapid changes the interlocked particles of isolate cannot reorientate promptly and are therefore repelled. With this treatment the isolate remains suspended in front of the pole shoes. Frequency and damping of the oscillating circuit are regulated to the optimum by observing the movement of the isolate. To increase the shaking action still more, a separating tube 4 capable of being rotated at the top and open at the bottom, is placed between the two pole shoes; through the tube support is a stirrer 5 which passes below the lower opening.

The isolate is first placed in a separating glass 6 filled with water or alcohol, which is slipped over the separating cylinder from below. The contents are then mixed to a slurry by the stirrer. With the magnetic field switched on without the oscillator, the magnetic portion collects in front of the pointed pole shoe, on the inner wall of the separating cylinder. Then the contact breaker is switched on, and the oscillating circuit adjusted. If necessary the cylinder may be rotated against the separating glass.

After the separating-out of non-magnetic particles is completed, a constant magnetic field is again applied, the movement of the cylinder stopped, and the separating glass removed. The magnetic fraction remains on the wall of the cylinder in front of the pole shoe, while the weakly magnetic or non-magnetic portion remains in the glass. The magnetic fraction is collected in a second glass and is immediately and thoroughly demagnetized.

Practical Separation Results

Illustrations of isolated and separated phases may add to the value of this survey. The isolate of an iron-phosphorus alloy containing 1·64%P consisted mainly of the phosphide Fe_3P, which is ferromagnetic. After treatment in the magnetic separator a small, somewhat finer non-magnetic portion remained. This proved to be pure non-magnetic Fe_3P, which occurs only in small amounts in the structure of the phosphoric iron under examination. Both fractions (Figs. 9*a* and *b*) were so completely separated from each other that the X-ray structural diagram in either case showed no trace of the other constituent. Micro-analysis also indicated very complete separation.

In other cases it has also been possible to separate three fractions, for example α-iron, wüstite, and manganese sulphide. The phases so far separated by means of this apparatus are given below.

Magnetically Separable Phases

Strongly magnetic: α-iron
Magnetic: Fe_3C Fe_3P
Slightly magnetic: FeO Fe_3O_4 $Fe_{21}Mo_2C_6$
Due to coalescence
or iron enrichment: Oxides Sulphides γ-phase
Non-magnetic: Fe_3P AlN Special carbides of alloying metals, e.g. Me_6C, $Me_{23}C_6$, Me_7C_3 Me_2C, MeC Martensite carbon Graphite σ-phase Oxides Sulphides γ-phase

APPLICATION OF ISOLATION METHODS

In the developments outlined, the improvement in the technique of the method and its application to metallurgical and metallographical problems often went hand in hand. A number of studies were concerned with deoxidation and the formation of oxide inclusions in steels,[14–20] and others with the formation and nature of sulphides existing in steels.[21, 5] The influence of nitrides on the properties of aluminium-killed steels was investigated with the aid of the electrolytic isolation method[22] and in individual cases it was found possible to isolate nitrides in the pure state from steel, using the separation method.[23]

The widest field is covered by investigations dealing with the composition of carbides in alloy steels,[24, 25, 26] the transformation behaviour of steels, and the associated carbide transformations.[27, 28, 29] To these are related recent investigations of carbide changes during long-duration creep tests[30] and the formation of intermetallic phases.[31, 32]

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The Determination of Hydrogen in Steel by a Carrier-gas Technique

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SYNOPSIS

It is shown that the hydrogen content of steel can be determined by heating the sample at about 650° C in a stream of an inert carrier gas. The evolved hydrogen is oxidized by a hot copper oxide–ferric oxide catalyst and the water determined by a Karl Fischer titration or gravimetrically. Evolution of the hydrogen occurs substantially at the same rate as in the well known vacuum heating technique and it is shown that the rate-controlling factor is the diffusion of the hydrogen within the solid sample.

Data are presented to show that the carrier-gas procedure has an accuracy comparable to that of the vacuum heating method. The procedure overcomes the need for vacuum apparatus and technique, and its simplicity should facilitate the determination of hydrogen in steelworks routine laboratories. 1622

INTRODUCTION

THE VACUUM HOT EXTRACTION method for the determination of hydrogen in steel was developed some years ago and this technique is commonly used at present for routine analysis. At one time the sample was melted (vacuum fusion) but this has been largely superseded by vacuum extraction of the solid sample at 600–700° C.

This technique is attractive since it required only a simple furnace assembly and, moreover, the gas evolved usually contains about 90–95% hydrogen; for control purposes, therefore, an analysis of the gas evolved is often unnecessary.

In spite of the simplifications introduced by solid vacuum extraction, many steelworks laboratories have continued to avoid hydrogen determinations since the apparatus required is expensive and fragile and requires personnel trained in high-vacuum techniques. Any analytical technique which is accurate and at the same time overcomes the need for vacuum treatment is therefore of particular interest to the steelworks laboratory.

The basic principles employed in the vacuum hot extraction method involve the use of elevated temperatures to increase the diffusivity of hydrogen in iron, together with the reduction of the hydrogen partial pressure to negligible proportions around the sample. The hydrogen atoms then diffuse to the surface of the specimen and are drawn off as molecular hydrogen (with traces of other gases such as CO and N_2) by the vacuum pumps; the gases are finally concentrated in a suitable vessel for measurement and analysis.

Theoretically the reduction of the hydrogen partial pressure around the steel sample may be accomplished by the use of a streaming carrier gas instead of vacuum extraction. The presence of the carrier-gas molecules might slightly decrease the rate of hydrogen evolution but would not prevent its quantitative extraction. Such a system could be operated at a total gas pressure of about 1 atm and would avoid the use of expensive vacuum pumps, etc.

The authors[1] have shown that a carrier-gas technique may be used for the determination of oxygen in steel, and Rooney and Barr[2] have experimented with a recirculating system containing nitrogen for the extraction of hydrogen from a sample heated to 600° C. They showed that complete hydrogen extraction occurred within 60 min, and therefore it should be feasible to base a practical method of hydrogen determination on the quantitative evolution into an inert carrier gas, followed by oxidation of the hydrogen to water, which in turn could be estimated by the Karl Fischer reagent. A similar system has previously been used by Heyn,[3] in which the water formed was determined gravimetrically by absorption in phosphorus

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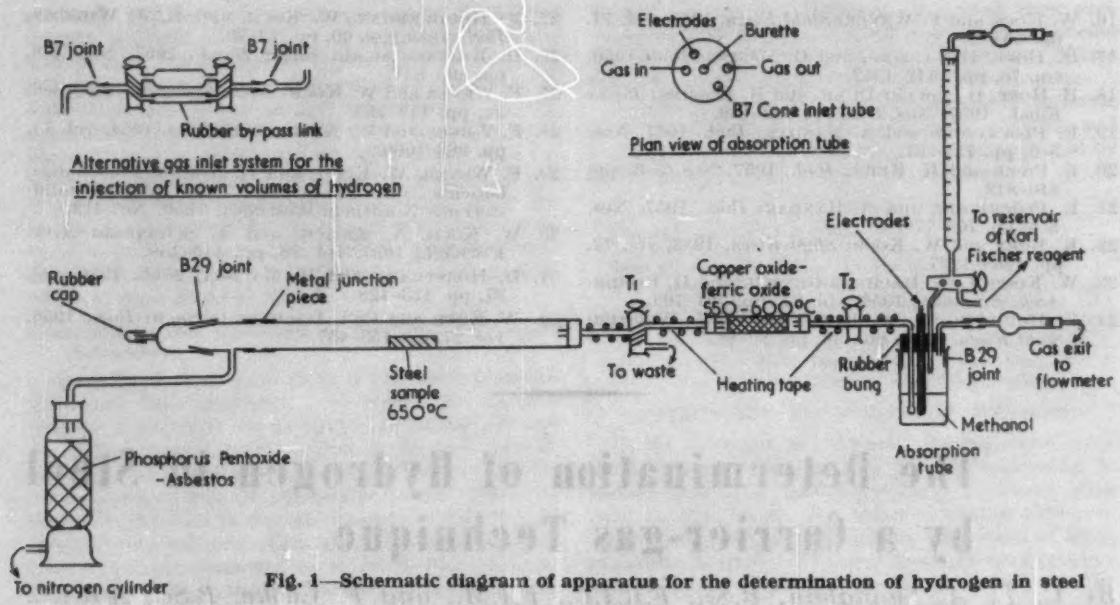


Fig. 1—Schematic diagram of apparatus for the determination of hydrogen in steel

pentoxide. Unfortunately the technique appeared to be unsuccessful but this may have arisen from the very low hydrogen contents of the samples employed.

The present report describes the development of a non-cycling carrier-gas (nitrogen) technique suitable for the routine determination of hydrogen in steel.

EXPERIMENTAL PROCEDURE

A schematic drawing of the apparatus used is given in Fig. 1. A steel sample of about 50 g is heated to about 650° C in a 1-in. dia. silica combustion tube fitted with a B 29 cone, socket, and sidearm at the gas entry end. Hydrogen diffusing from the sample is carried along in the stream of dry nitrogen (flow rate 2 l./h) and oxidized over the copper oxide–ferric oxide mixture (Arneil catalyst)[4] held at 550–600° C. The resulting water is absorbed in 10 ml of methanol contained in the absorption tube and titrated with Karl Fischer reagent from a 5-ml burette using a 'dead-stop' end-point. As can be seen from Fig. 1, suitable precautions are taken to prevent the ingress of moisture to the absorption tube, the burette, and the reservoir of Karl Fischer reagent, whilst an electrical heating tape wound around the line leading from the combustion tube to the absorption tube maintains a temperature of around 70° C, thus preventing condensation of moisture from the carrier-gas stream.

Quantitative Conversion of Hydrogen to Water

Since the technique relies on the quantitative conversion to water of the hydrogen evolved from the steel sample, a preliminary series of experiments was made in which known amounts of pure hydrogen were introduced to the apparatus and compared with the values estimated by the Karl Fischer titration. A gas-sampling tube containing a known amount of hydrogen was inserted into the line between the drying tower and the combustion tube. By using the rubber by-pass link (inset, Fig. 1), the train could be purged with nitrogen until a stable blank rate was obtained (typical value 0·3 mg/h of water at a nitrogen flow rate of 2 l./h). After titrating any water in the methanol, the stopcocks of the gas-sampling tube were opened to introduce the hydrogen to the system. The methanol was periodically titrated with the Karl Fischer reagent until the rate of water absorption decreased to the original blank rate; this normally occurred in about 30 min. Table I shows a comparison of the amounts of hydrogen injected with the corresponding values determined by titration. The estimated error in measurement is $\pm 0{\cdot}1$ ml of hydrogen on both the injected volume of hydrogen

Table I

DETERMINATION OF KNOWN VOLUMES OF HYDROGEN BY MEANS OF KARL FISCHER REAGENT

Volume of hydrogen fed into train, ml, N.T.P.	Volume of hydrogen determined, ml, N.T.P.
5·1	5·2
4·8	5·0
4·6	4·7
4·4	4·3
3·9	4·0
3·7	3·6
3·3	3·4
3·1	3·2
2·9	2·8
2·2	2·3
2·1	1·9
2·0	1·9
1·7	1·6
1·4	1·4
1·3	1·2
1·1	1·0
0·8	0·5
0·6	0·4
0·4	0·4

and on the accuracy of titration with the Karl Fischer reagent.

Rate of Hydrogen Extraction from Steel Samples

To examine whether the presence of a carrier gas would affect the rate of hydrogen evolution from a steel sample, a comparison was made of the hydrogen extraction rates obtained from similar steel samples using the above technique and the vacuum heating method.[5] The procedure using the equipment in Fig. 1 was as follows. With tap T1 turned off the carrier gas flow rate was increased so that when the B29 socket was removed for sample introduction the velocity of the gas stream through the B29 cone was sufficient to prevent the ingress of water vapour from the atmosphere. The B29 socket was then removed, a weighed and degreased steel sample placed within the cone extension and the socket replaced. T1 was adjusted to pass the carrier gas to waste for a further 5 min before reverting to the flow rate of 2 l./h. After titrating any water present in the methanol, T1 was again turned off and the steel sample pushed into the hot zone by means of a clean steel rod inserted through the previously opened tubulure on the B29 socket. The rubber end-cap was then replaced and tap T1 turned to pass the carrier gas through the copper oxide–ferric oxide furnace. Titrations of the absorbed water were made at intervals after 30 min running. Figure 2 shows comparisons of hydrogen evolution rates using this technique and the vacuum heating procedure in conjunction with two pairs of steel samples. Each sample was rectangular in shape with dimensions $\frac{1}{2}$ in. × $\frac{1}{2}$ in. × $1\frac{1}{2}$ in.

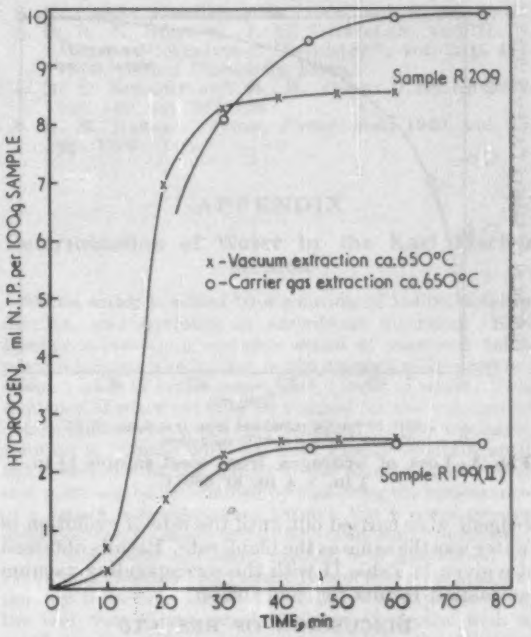


Fig. 2—Evolution of hydrogen from a heated steel *in vacuo* and in a stream of an inert carrier gas. Sample dimensions about $1\frac{1}{2}$ in. × $\frac{1}{2}$ in. × $\frac{1}{2}$ in.

Analysis of Steel Samples

The high diffusivity and marked segregation effects of hydrogen in iron and steel materials make it difficult to obtain samples having precisely the same hydrogen content. Even when the samples are cut from adjacent positions within a billet, small variations in the hydrogen contents occur and these differences increase if the samples are stored for different time periods before hot extraction.

In comparing the accuracy of the carrier-gas technique with the vacuum extraction procedure, the steel samples comprised blocks $\frac{1}{2}$ in. × $\frac{1}{2}$ in. × $1\frac{1}{2}$ in. taken from adjacent positions at the centre of billets and slabs of various thicknesses up to 5–6 in. The samples were all low-carbon steels of approximate analysis 0·06–0·08%C, < 0·005%Si, 0·3–0·4% Mn, 0·02–0·05%S, 0·01–0·05%P.

The mode of sample introduction was precisely that given above and titrations with the Karl Fischer

Table II

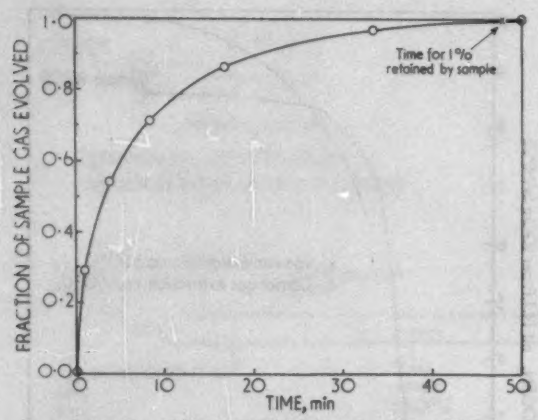
HYDROGEN CONTENTS OF STEELS BY THE VACUUM HEATING AND CARRIER-GAS METHODS

(a) Karl Fischer technique

Sample	Hydrogen determined (ml N.T.P. per 100 g)			
	Carrier gas method	Vacuum heating method	Average of Series: Carrier gas method	Average of Series: Vacuum heating method
R 199 A	2·4 2·5	2·6 2·6	2·45	2·60
R 199 B	3·3 2·4 2·3 2·9	2·6 2·5 2·5 3·0	2·73	2·65
R 199 C	2·0 1·8 2·7 2·8 2·4	2·4 3·0 2·7 2·6	2·34	2·68
R 189 A	1·0 1·5	1·0 1·0	1·25	1·00
R 112	1·2 0·9 0·8 0·7	1·2 0·8	0·90	1·00
R 196	1·0 1·9 1·7 2·0	1·5 1·3	1·65	1·40
R 113	1·8 1·2 0·8	1·5 1·6	1·27	1·55
R 211	1·4 1·3	1·0 1·1	1·35	1·05
R 201	1·2 0·7	1·1 0·8	0·95	0·95

(b) Gravimetric (absorption in Anhydrone)

R 189 B	1·5 0·5 0·9 1·8 1·5 2·1 2·2	1·0 1·1 0·9 2·6 1·3 2·8	1·50	1·62
M 345/2	1·1	1·3		
M 347/2	1·1	1·1		
G 890/2	1·0	1·3		



$D = 1{\cdot}09 \times 10^{-4}$ cm²/s, calculated from $D = D_0 \exp.-E/RT$
$D_0 = 1{\cdot}65 \times 10^{-2}$ cm²/s $E = 9200$ cal/g-atom

Fig. 3—Loss of hydrogen from steel sample 1½ in. × ½ in. × ½ in. at 650° C

reagent were carried out until the rate of evolution of water was the same as the blank rate. Results obtained are given in Table II with the corresponding vacuum extraction results for comparison.

DISCUSSION OF RESULTS

Quantitative Conversion of Hydrogen to Water

In general, satisfactory agreement was obtained between the amounts of hydrogen introduced to the carrier gas system and the amounts determined by the Karl Fischer titration. With one exception, the differences were not more than 0·2 ml and were within the anticipated experimental error.

Rate of Hydrogen Extraction from Steel Samples

A comparison of the curves shown in Fig. 2 shows that the overall extraction rate for the carrier-gas technique is similar to that for the vacuum heating method. This strongly suggests that the rate-determining factor in both techniques is the diffusion of hydrogen through the body of the sample and that little or no advantage is to be gained by increased purging rate or vacuum extraction speeds.

Diffusion of hydrogen from a sample will be most rapid when the surface concentration is maintained at zero and if, under these conditions, the evolution/time curve is similar to those obtained above, it may fairly be assumed that sufficiently high purging rates or vacuum extraction speeds are being employed for the shape of samples used.

It is possible to calculate the hydrogen evolution/time curve at 650° C for rectangular steel samples (dimensions ½ in. × ½ in. × 1½ in.) from the value of the hydrogen diffusivity and Fick's second law.

The change in concentration of hydrogen with time at any point in a bar is given by the three-dimensional form of Fick's second law

$$\frac{\partial c}{\partial t} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2}\right)$$

where c = hydrogen concentration (amount/cm³), t = time(s), x, y, and z are the Cartesian co-ordinates (cm) of the position, and D is the diffusivity (cm²/s).

This equation may be solved in conjunction with the boundary conditions that at $t = 0$, $c = c_0$ for any position within the bar and at $t > 0$, the surface concentration is zero. The solution $c = f(D, t, x, y, z)$ provides a value for the hydrogen concentration at any point within the bar at any time. By evaluating

$$\int_0^v C\,dv$$

at any time level t, the amount of hydrogen remaining in the whole bar can be calculated. It is thus possible to draw an extraction/time curve for a bar of constant dimensions and hydrogen diffusivity defined by the above boundary conditions. Figure 3 shows such a curve for a 1½ in. × ½ in. × ½ in. rectangular steel sample; the diffusivity of hydrogen at 650° C ($1{\cdot}09 \times 10^{-4}$ cm²/s) has been calculated from the equation recommended by Barrer[6]

$$D = D_0 \exp - E/RT$$

where D = diffusivity in cm²/s, $D_0 = 1{\cdot}65 \times 10^{-2}$ cm²/s, and $E = 9200$ cal/g-atom.

A comparison of Figs. 3 and 2 shows that the hydrogen evolution rates in the carrier-gas technique and the vacuum heating procedure are controlled mainly by diffusion. Although the time for, say, 99% extraction is a little longer in practice than would be expected by diffusion control, an allowance must be made for the time required for the steel sample to reach 650° C from room temperature.

Analyses of Steel Samples

Because of the difficulty in obtaining samples of constant hydrogen content, comparison of the results obtained by the carrier gas and vacuum heating methods is based principally on a comparison of the average hydrogen content of each series. The average values for Series R 199 A and B, R 112, and R 201 are considered to be fully satisfactory, the differences between the averages being less than ±0·2 ml hydrogen per 100 g. Where sufficient data were available, a statistical examination has been made of the remaining series in which the average values

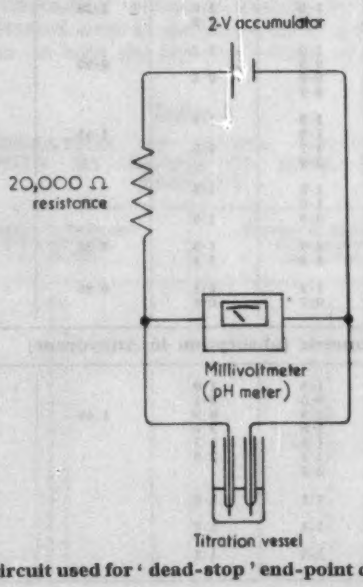


Fig. 4—Circuit used for 'dead-stop' end-point detection

differed by more than 0·2 ml per 100 g, i.e. in the case of Series R 199 C, R 106, and R 113. In each case it has been shown that there is no significant difference between the mean values, and these latter sets of results are therefore considered to be in reasonable agreement. The results generally may thus be taken as offering direct support of preliminary findings that the carrier-gas technique is suitable for the accurate determination of hydrogen.

Several different methods are available for determining water vapour in a carrier-gas stream:

(i) The Karl Fischer technique
(ii) Direct gravimetric determination by absorption in, for example, Anhydrone
(iii) Reaction with cinnamoyl chloride followed by the volumetric determination of the HCl evolved
(iv) Reaction with magnesium nitride to give ammonia which may be subsequently determined by use of the Nessler reagent
(v) Freezing out.

The Karl Fischer reagent was used initially in view of its ready availability in many laboratories, and because a volumetric finish is more suitable for confirming that the final rate of evolution is equivalent to the blank rate. A gravimetric finish by absorption in Anhydrone has also been found to be suitable and the results obtained in this manner are listed in Table II*b*. Because of the small amount of water collected a semi-microbalance is necessary to obtain the required sensitivity, the water being collected in a Pregl micro-absorption tube packed with Anhydrone. It is intended to investigate the potentialities of methods (iii) and (iv). Method (v), although very sensitive, requires vacuum equipment and the use of freezing mixtures.

CONCLUSIONS

(1) A carrier-gas technique has been evolved for determining the hydrogen content of steel with an accuracy comparable to that obtained with the well known vacuum heating procedures.

The method results in a considerable simplification of the equipment and technique normally associated with hydrogen determination and should facilitate routine determinations in steelworks laboratories.

(2) The presence of the carrier gas does not appreciably influence the rate of hydrogen evolution which is mainly controlled by diffusion of the hydrogen within the steel sample.

(3) Two methods of determination of the water resulting from oxidation of the hydrogen have been used and found to be satisfactory.

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APPENDIX

Determination of Water by the Karl Fischer Method

When water is added to a solution of iodine, sulphur dioxide, and pyridine in anhydrous methanol (Karl Fischer solution), a complex series of reactions takes place involving a reduction in the amount of free iodine; about 1 mole of iodine reacts with 1 mole of water. This sequence of reactions may be utilized for the volumetric determination of water in methanol. The methanol solution is titrated with the Karl Fischer solution until the occurrence of free iodine in the titration flask. The end-point can be determined by observing the appearance of a brown coloration (free iodine), but a more precise detection can be made using the 'dead-stop' technique.

The dead-stop end-point method was introduced by Foulk and Bawden,[1] and many references to its application are to be found in the literature.[2] It depends upon the fact that if two small platinum electrodes with a small applied potential are immersed in the solution being titrated, then no current flows until the end-point (i.e. excess iodine) is reached. This phenomenon has been attributed to the polarization of the cathode with hydrogen which is removed by excess iodine although other reasons have been proposed.[3]

A second variation of the dead-stop technique is to maintain a constant current through the titration vessel and to note the sharp change of potential across the cell which occurs at the end-point.[4] This is conveniently arranged by incorporating a high resistance in series with the cell so that the total resistance of the circuit is approximately constant throughout the entire titration.

Figure 4 shows the circuit used in conjunction with the carrier-gas apparatus described in the present paper. The Karl Fischer reagent was prepared by diluting the commercially available material (B.D.H. Laboratory Reagent 1 ml ≡ 5 mg H_2O) with 'anhydrous' methanol to give a solution of strength 1 ml ≡ about 1 mg H_2O. The reagent was standardized against known amounts of water (about 5 mg), weighed by means of a semi-microbalance into small glass 'cups' which were introduced into the titration vessel through the B7 cone on the cap of the absorption tube (*see* plan view in Fig. 1). If a sufficiently accurate balance is not available, the reagent can be standardized against a standard solution of water in 'anhydrous' methanol, making allowance for the traces of water already present in the alcohol.

1 mg H_2O ≡ 1·244 ml of H_2 at N.T.P.

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ANDREW CARNEGIE SCHOLARSHIP REPORT

The Kinetics of Bainite Formation in a Plain Carbon Steel

By P. Vasudevan, Ph.D., L. W. Graham, Ph.D., and H. J. Axon, D.Phil.

SYNOPSIS

The rate of isothermal decomposition of austenite has been studied in the temperature range 400–100° C for a 0·97%C plain carbon steel. Transformation was followed by a conventional dilatometer method and by the chemical analysis of combined carbon in partly or completely reacted specimens using the Eggertz colour-carbon method. A marked change in the kinetics of decomposition was observed at 350° C. Above 350° C dilatometric and colour-carbon measurements both give the same transformation/time characteristics, but at temperatures below 350° C the early stages of carbide precipitation, as measured by the Eggertz test, lag behind the transformation as measured dilatometrically. Activation energies for transformation above and below 350° C have been evaluated and they approximate the activation energies for carbon diffusion in austenite and in supersaturated ferrite respectively.

1534

INTRODUCTION

KO AND COTTRELL[1] HAVE SUMMARIZED the main features of the bainite reaction which takes place isothermally in the temperature range between the pearlitic and martensitic modes of decomposition. In general it appears that the formation of bainite from austenite is similar to the formation of pearlite in that the reaction proceeds by the relatively slow migration of an interface. There are, however, similarities to the formation of martensite in that surface-relief effects appropriate to a condition of coherency at the austenite/bainite interface have been observed.[1]

The microscopic appearance of bainite in a plain carbon steel varies with the temperature at which it is formed, from a feathery open structure (upper bainite) at higher temperatures to a structure very similar to lightly tempered martensite (lower bainite) at temperatures closer to the M_s. Recently electron microscope work[2, 3] has provided a more detailed differentiation between the bainitic products of a plain carbon eutectoid steel in the temperature range 260–510° C. Transformation at temperatures below about 320° C results in the presence within the bainite lenses of small plates of carbide oriented laterally with respect to the long axis of the lens. However, at higher transformation temperatures the bainite lenses are thicker and the carbide plates within them are oriented parallel to the long axis. Even higher transformation temperatures are associated with larger carbide plates, which tend to be arranged in stringers to produce under the optical microscope the well known feathery upper bainite.

There is no published information on precise reaction rates corresponding to upper and lower bainite as distinguished by the electron microscope, hence the first object of the present work was a precise re-investigation of reaction kinetics in the upper and lower bainite ranges. For this two techniques were employed: a conventional dilatometer method and, in view of the difference of carbide morphology, the Eggertz or colour-carbon method of chemical analysis of partly or wholly reacted specimens. The use of the two methods in conjunction on the same steel similarly heat-treated is particularly valuable since the dilatometric method records volume changes which may arise from the interplay of matrix transformations and carbide precipitation whilst the colour-carbon method of analysis records the amount of carbon which has precipitated as carbide during the transformation.

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EXPERIMENTAL METHODS

The material used in all tests was a plain carbon steel of the following composition:

C, %	Ni, %	Cr, %	Cu, %	Si, %	Mn, %
0·97	0·14	0·14	0·13	0·13	0·16

It was received in the form of $\frac{1}{2}$-in. dia. round bar and was reduced to $\frac{1}{4}$ in. dia. Specimens were machined from this rod, which was in the divorced pearlite condition.

The quenching dilatometer was similar in general construction to that used by Griffiths, Pfeil, and Allen.[4] Nail-shaped specimens 1·2 in. long × 0·125 in. dia. were seated in a U-shaped silica cradle constructed of $\frac{3}{16}$-in. wide silica strip welded to the end of a length of $\frac{1}{4}$-in. bore silica tube. The head of each specimen was located inside the silica tube while the pointed end rested in a conical depression in the base of the cradle. Length changes were transmitted to a dial gauge graduated in 0·0001 in. by means of a $\frac{1}{8}$-in. dia. silica rod seated in a hole machined in the nail-head of the specimen. The silica component of the dilatometer was clamped to a water-cooled copper cylinder above which the dial gauge was firmly mounted. The whole dilatometer was mounted vertically on a rigid metal frame which could be moved vertically in a plane and also swung about a vertical axis in the same plane. This framework was arranged above an asbestos-topped table into which a Nichrome-wound austenitizing furnace and a lead–bismuth quenching bath were recessed, entry to the furnaces being through holes cut in the asbestos sheet. In practice the transfer of the specimen from the austenitizing furnace to the quenching bath consisted of raising the dilatometer frame vertically, swinging it through an arc until the dilatometer came over the hole of the isothermal bath, and lowering the dilatometer into this hole—a process taking about 2 s. A carbon jacket was constructed to rest on the shoulders of the dilatometer cradle and to surround

the specimen during the austenitizing treatment and during the transfer process, but was prevented from entering the isothermal bath by the size of the entry hole. This carbon jacket served the dual purpose of minimizing decarburization during heat-treatment and minimizing heat loss from the specimen during transfer.

A 16-mm cine camera was used to record rapid changes of length during the quenching process. The quenched specimen reached a temperature within 10° C of the quenching bath in 5 s, the quenching bath being stirred during the quench.

The Eggertz colour-carbon method of chemical analysis involves the dissolution of a known mass of steel in nitric acid under strictly standardized conditions to develop a brown colour, the intensity of which is proportional to the amount of *carbide* in the sample. Thompson and Chaudhuri[5] have described the use of this method to investigate the condition of the carbon in quenched and tempered steels.

In the present experiments care was taken to employ specimens of a size and shape similar to those used in the dilatometric work, hence quenching rates were similar. Specimens were austenitized in a Nichrome-wound furnace mounted directly above a lead–bismuth quenching bath. At the completion of the austenitizing treatment specimens were plunged into the stirred quenching bath from which they were withdrawn and water-quenched after a predetermined time of isothermal transformation. After being weighed the specimens were dissolved in A.R. HNO_3, 10 ml of acid being used for each 0·25 g of metal. Eight specimens were dissolved for each treatment and the mean of the eight results taken. Dissolution was conducted at 100° C for 10 min, and in no instance was any undissolved residue found after this treatment. After being cooled the colour intensity of each solution was measured on a Hilger photoelectric absorptiometer.

In both the dilatometric and colour-carbon experiments decarburization of the specimens was effectively prevented by nickel plating them and by austenitizing in a furnace atmosphere of pure dry nitrogen. With

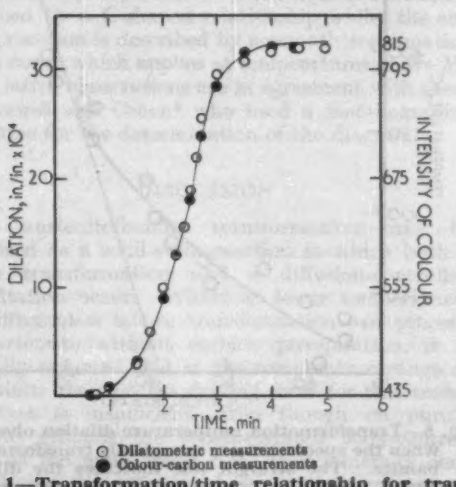

Fig. 1—Transformation/time relationship for transformation to upper bainite at 365° C

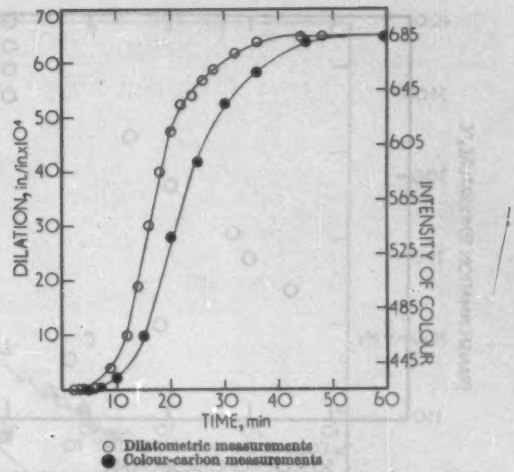

Fig. 2—Transformation/time relationship for transformation to lower bainite at 266° C

the dilatometric method it was found that decarburization was entirely prevented by the use of the carbon jacket and experiments conducted with and without nickel plating indicated that the presence of the nickel had no detectable effect on the dilatometric results, or on the metallographically determined percentage martensite/temperature relationship.

The nickel layer was removed from the analytical specimens by careful mechanical abrasion before the specimens were dissolved.

Throughout the work a standard austenitizing treatment of 10 min at 900 ± 5° C was employed, and the liquid-metal isothermal baths were controlled to within ± 2° C of the required transformation temperature.

EXPERIMENTAL RESULTS

The M_s temperature of the steel was determined metallographically by the method of Greninger and Troiano[6] using a point-counting technique to estimate the amount of martensite formed on quenching to various temperatures below the M_s. Extrapolating the percentage martensite/temperature relationship to zero martensite gave an M_s value of 200° C. Most isothermal experiments were conducted in the temperature range 400° C–M_s, although a few experiments were conducted below the M_s temperature.

The transformation curves obtained from both the colour-carbon and the dilatometric measurements were of conventional form; both colour intensity and dilation increasing as transformation progressed. The completion of the reaction was confirmed by microscopic examination of etched microsections.

The isothermal reaction curves fall into two well defined groups. At temperatures above about 350° C the transformation/time curves obtained by each method at the same temperature coincide as shown in Fig. 1. Below about 350° C the colour-carbon curves lag behind the dilatometer curves as indicated in Fig. 2. At any temperature the magnitude of the deviation is small near the start and finish of transformation and attains a maximum value at an intermediate amount of transformation. Furthermore the

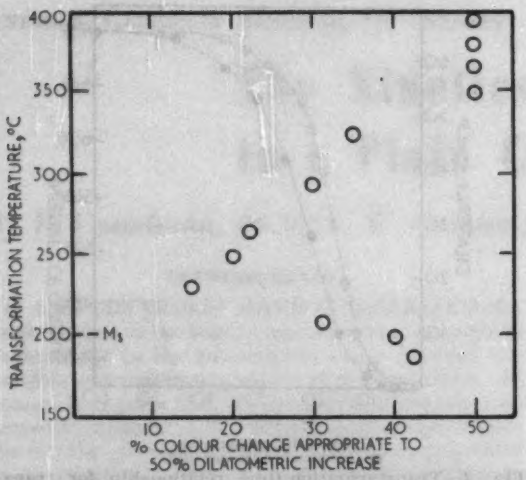

Fig. 3—Transformation temperature/percentage colour-carbon change, observed at 50% dilational change (100% colour at any temperature is the total colour developed after complete isothermal transformation at that particular temperature)

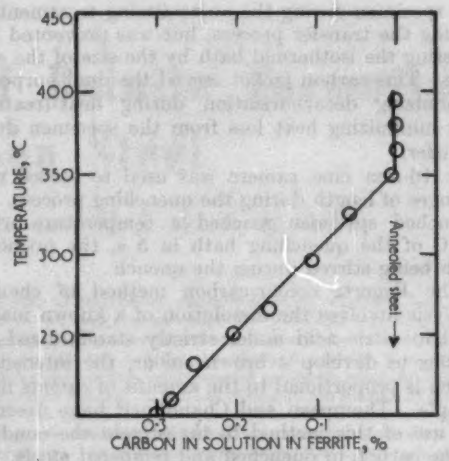

Fig. 4—Transformation temperature/percentage of carbon in solution in the ferritic component of specimens completely transformed to bainite

magnitude of the deviation increases as the reaction temperature is lowered. This is indicated in Fig. 3, in which the percentage change of colour carbon appropriate to a 50% increase of total dilation is plotted against isothermal transformation temperature. Dilational change is generally taken as proportional to the volume of bainite formed, whilst change of colour intensity may be regarded as proportional to the carbide precipitated during the transformation; thus at temperatures above 350° C the rate of lattice transformation to bainite keeps pace with the rate of carbide precipitation whereas at progressively lower temperatures, down to the M_s, carbide precipitation lags behind the lattice transformation in the early stages, but becomes more rapid towards the end of the isothermal process. There is some indication that on trespassing into the martensite range this effect begins to decrease.

In Fig. 3 the percentage colour intensity refers to the proportion of the total colour developed for complete transformation at each temperature, but there are interesting temperature-dependent variations in the absolute magnitude of both dilation and colour change which accompanies complete transformation. For complete transformation above 350° C the colour intensity is found to be equal to that obtained with annealed material (where all the carbon is in the form of massive cementite and the ferrite is virtually free from dissolved carbon), whilst below 350° C the colour intensity associated with complete transformation decreases progressively with decreasing temperature. These observations are shown graphically in Fig. 4, in which the colour intensities are expressed in terms of the amount of carbon remaining in the solution in the fully reacted specimens on the assumption that all the combined carbon is in the form of Fe_3C. The dilation associated with complete transformation is reported for the same temperature range in Fig. 5, together with the dilation which would be expected for complete transformation to Fe_3C and carbon-free ferrite. The latter estimate is made from a knowledge of the length changes undergone on slow cooling from the austenitizing temperature, together with the length of specimens quenched to the isothermal reaction temperature. The difference between these two lengths for a particular temperature is a measure of the amount of expansion expected for the transformation of austenite to a mixture of Fe_3C and carbon-free ferrite. It may be seen from Fig. 5 that below 350° C the dilation observed in an isothermal transformation from austenite to bainite is greater than that which would be expected if the products were Fe_3C and carbon-free ferrite. Similar results have been reported by Pfeil, Griffiths, and Allen[4] and by Russel and Mavrocadatos[7] for low-alloy steels. These results indicate that below a temperature of 350° C the

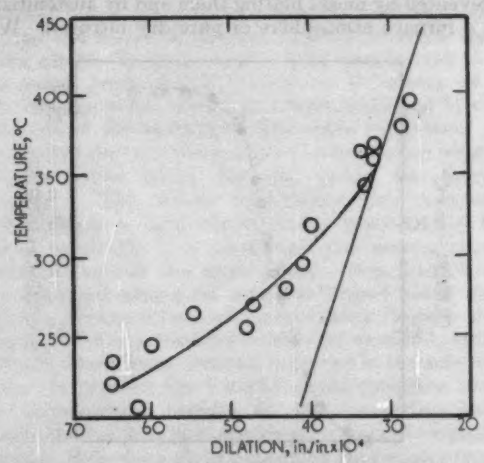

Fig. 5—Transformation temperature/dilation observed when the specimens are completely transformed to bainite. The straight line indicates the dilation which would be expected if the transformation products were Fe_3C and carbon-free ferrite

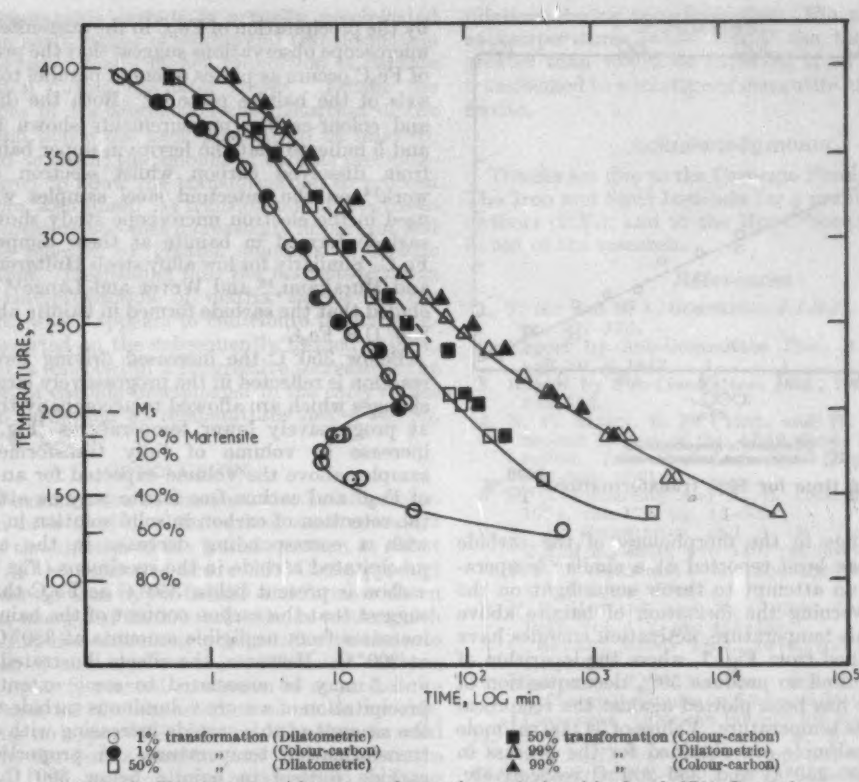

Fig. 6—Temperature/time transformation relationship for 0·97% C steel

amount of carbon precipated during isothermal transformation progressively decreases and the resulting dilation progressively increases as the isothermal transformation temperature is lowered.

A change in the character of the austenite/bainite reaction at 350° C is also visible in the temperature/transformation time-diagram in Fig. 6. At temperatures below the M_s the start of the bainite reaction is described by a C-shaped relationship whilst the end of the reaction is described by a smooth continuation of the curve which applies at temperatures above M_s. These latter observations are in agreement with those of Howard and Cohen[8] who used a metallographic technique for the determination of the diagram.

DISCUSSION

The austenite/bainite transformation may be visualized as a solid-state reaction in which both a lattice transformation and a diffusion-controlled precipitation occur. Whilst at lower temperatures the diffusionless lattice transformation can proceed to martensite without carbide precipitation, it is generally assumed that in the temperature range of the bainite reaction the driving force for this transformation is insufficient, even though on purely chemical grounds the supersaturated body-centred lattice is the more stable.[9, 10] It is generally considered that the difference between the temperature at which the supersaturated b.c. lattice becomes stable relative to the f.c.c. lattice, calculated in terms of chemical free energies, and the observed onset of the reaction (M_s) is accounted for by the non-chemical energy requirements of the transformation. For example the driving force must be sufficient to provide for an increase in surface, volumetric, and shear-strain energies and probably also to overcome the mechanical restraint of the matrix surrounding the plates of transformation product.

It has been suggested that the formation of bainite is consequent upon this balance of energies becoming more favourable,[1] the austenite transforming into a product which is a thermodynamically and kinetically practicable compromise. Assuming that supersaturated ferrite nuclei are present in the austenite it is considered that the balance of energies becomes favourable, allowing bainite plates to form, mainly through the reduction of the energy requirements consequent upon the density change which occurs when carbon is removed from the supersaturated ferrite. This may be achieved either by the diffusion of carbon from the supersaturated b.c. structure into the surrounding austenite matrix or by the precipitation of carbide within the supersaturated b.c. structure. On theoretical grounds the former might be expected to predominate at high temperatures and the latter at low temperatures.[1]

The change of reaction kinetics observed at 350° C is of particular interest since the material used in the present work is similar in composition to that for

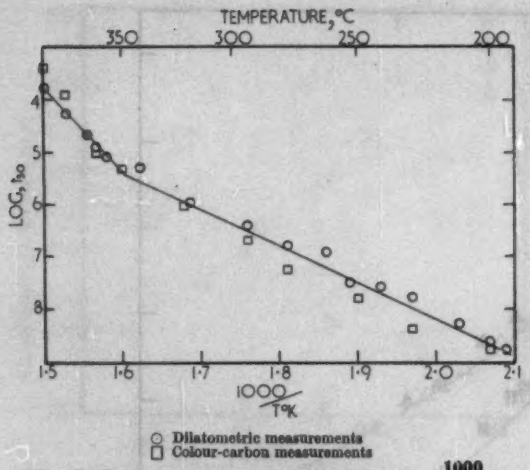

Fig. 7—Log time for 50% transformation/$\frac{1000}{T}$ °K

which a change in the morphology of the carbide precipitate has been reported at a similar temperature.[2, 3] In an attempt to throw some light on the processes governing the formation of bainite above and below this temperature, activation energies have been determined from Fig. 7, where the logarithm of the time required to produce 50% decomposition of the austenite has been plotted against the reciprocal of the absolute temperature. Values of 34,000 cal/mole and 14,000 cal/mole are obtained for the process in the range 400–350° C and 350–200° C respectively. The value of 34,000 cal/mole is close to that (31,000 cal/mole) reported by Wells, Batz, and Mehl[11] for the activation energy of carbon diffusion in the austenite of a 1%C steel. On the other hand Roberts, Averbach, and Cohen[12] have obtained a value of 16,000 cal/mole for the activation energy of carbon diffusion in supersaturated ferrite, which corresponds reasonably with the value of 14,000 cal/mole obtained for the activation energy of bainite formation in the temperature range 350–200° C. These activation energies suggest that the decomposition of austenite to bainite at temperatures above 350° C is controlled by the diffusion of carbon in austenite, whilst at lower temperatures the controlling factor is the diffusion of carbon in supersaturated ferrite, and taking into account the reported difference in the morphology of the carbides above and below this temperature it is possible to construct a reasonably consistent picture of the process.

For upper bainite, forming above 350° C, the growth of bainite plates appears to depend on the outward diffusion of carbon into the surrounding austenite as suggested by Ko and Cottrell. This results in the carbon enrichment of the austenite surrounding the bainite plates.[13, 14] The enrichment leads to an increase in the stability of the austenite, and indeed the carbon content of the austenite surrounding carbide-free bainite plates in low-alloy steels may be increased to such an extent that the austenite has been retained on cooling to room temperature owing to the depression of the M_s.[15] The growth of the ferrite component of the bainite thus depends on the removal of carbon from the enriched austenite rim. This occurs by the precipitation of Fe_3C in the austenite. Electron microscope observations suggest that the precipitation of Fe_3C occurs as plates oriented parallel to the major axis of the bainite plate.[2, 3] Both the dilatometric and colour-carbon measurements shown in Figs. 4 and 5 indicate that the ferrite in upper bainite is free from dissolved carbon whilst electron diffraction work[16] on the eutectoid steel samples which were used in the electron microscope study show that the carbide formed in bainite at these temperatures is Fe_3C. Similarly for low alloy steels Hultgren,[17] Honda and Murakami,[18] and Wever and Lange[19] have concluded that the carbide formed in bainite above about 300° C is Fe_3C.

Below 350° C the increased driving force for the reaction is reflected in the progressively larger volume changes which are allowed to accompany the reaction at progressively lower temperatures (Fig. 5). The increase in volume of fully transformed bainite samples above the volume expected for an aggregate of Fe_3C and carbon-free ferrite may be attributed to the retention of carbon in solid solution in the ferrite with a corresponding decrease in the amount of precipitated carbide in the specimens (Fig. 4). If the carbon is present below 350° C as Fe_3C these results suggest that the carbon content of the bainitic ferrite increases from negligible amounts at 350° C to 0·3% at 200° C. However, the effects illustrated in Figs. 4 and 5 may be associated to some extent with the precipitation of a more voluminous carbide than Fe_3C, the amount of this carbide increasing with decreasing transformation temperature. A proportion of the carbide formed in bainite below 300° C has been identified with the hexagonal ϵ carbide of suggested formula $Fe_{2\cdot4}C$.[12] It has been shown by precision length measurements[20] and by X-ray investigation[21] that ϵ carbide has a larger specific volume than Fe_3C.

In the case of bainite formed below 350° C the activation energy and the electron microscopic observation of laterally oriented carbide particles within the bainite plates suggest that the propagation of lower bainite is controlled by the precipitation of carbide within the supersaturated ferrite rather than in the immediately surrounding rim of enriched austenite. The process may be regarded as the transformation of a region of austenite to one of supersaturated ferrite, which involves an increase in volume of the transformed region with a consequent back-pressure exerted by the matrix on the transformed region preventing further transformation by growth of that particular region. Subsequent precipitation of carbide within the supersaturated ferrite produces a decrease in volume of the transformed region with a consequent decrease in the back-pressure exerted by the matrix and hence growth of the transformed region may continue. It may be noted that as the transformation temperature is lowered the degree of supersaturation in the completely transformed specimens increases, probably because the progressively increased driving force for transformation means that less relaxation of the matrix back-pressure is required for the reaction to proceed.

Some further support for the back-pressure concept is given in Fig. 3, for as the transformation temperature is lowered, a progressively smaller proportion of the

total precipitatable carbide is actually precipitated during the early stages of isothermal transformation with a correspondingly higher proportion of carbide precipitation during the later stages. During the early stages of transformation the distortion of the matrix, and hence the back-pressure to be relieved, is likely to be small; the amount of carbide precipitation required to allow the transformation to proceed is, therefore, also small. As transformation progresses the back-pressure becomes increasingly important and has to be relieved by greater amounts of carbide precipitation. Trespassing into the martensite range involves the production of matrix strains by the martensite, which appears to contribute to the back-pressure exerted on the subsequently formed bainite. This effect is reflected in a progressive increase in the proportion of carbide precipitated in the early stages of bainite formation at temperatures below the M_s, as shown in Fig. 3.

CONCLUSION

Careful examination of the austenite/bainite transformation in a 0·97% plain carbon steel reveals a change in the kinetics of the transformation at about 350° C. At temperatures above 350° C the product may be identified as upper bainite and forms with an activation energy of 34,000 cal/mole, a value which suggests that the controlling process may be the rate of diffusion of carbon in austenite. Chemical analysis of the completely reacted specimens of upper bainite indicate that all the carbon is present as carbide, there being no appreciable amount of carbon in solid solution in the ferrite component. At temperatures below 350° C the product may be identified as lower bainite and forms with an activation energy of 14,000 cal/mole, a value which suggests that the controlling factor may be the rate of diffusion of carbon in supersaturated ferrite. Chemical analysis of the completely reacted specimens of lower bainite suggests that all the carbon is not precipitated as carbide; some being present in supersaturated solid solution in the ferrite component of the bainite. Chemical analysis of the partly transformed specimens suggests that the rate of carbide formation is less than the rate of lattice transformation in the early stages of the isothermal reaction but the reverse holds during the later stages.

The results obtained by chemical analysis of the carbide contents of fully reacted upper and lower bainites are supported by the magnitudes of the dilations during transformation. For transformation at temperatures below 350° C the total dilation is greater than would be expected if all the austenite transformed to a mixture of cementite and carbon-free ferrite.

Acknowledgments

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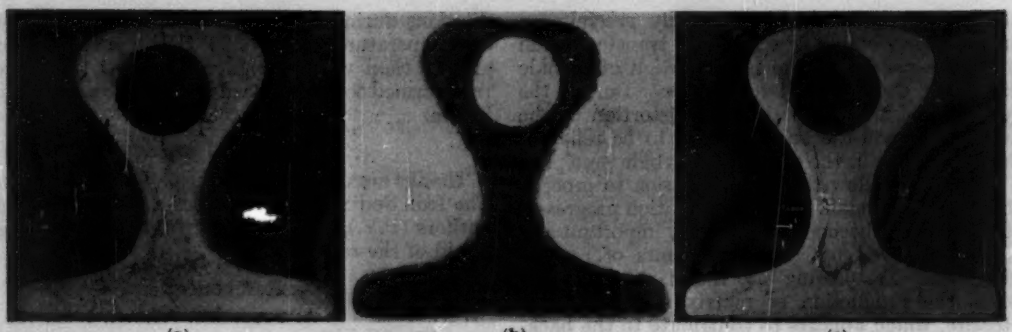
Examination of an Early Bessemer Rail

TO MARK the centenary of the successful experiments carried out on the Bessemer process by Mr. G. F. Göransson, founder of Sandvikens Jernverks AB (*J.I.S.I.*, 1958, July, vol. 189, pp. 201–204), The Iron and Steel Institute presented the Company with a section cut from a rail rolled at the Dowlais Works in 1856 from material made in an early cast by Mr. (later Sir Henry) Bessemer. The presentation was made by the Secretary, Mr. K. Headlam-Morley, during the centenary celebrations at Sandviken on 18th July (*J.I.S.I.*, 1958, Sept., vol. 190, p. 79).

The section was taken from a specimen presented to The Iron and Steel Institute in 1900 by Mr. Edward Riley (*J.I.S.I.*, 1901, No. 1, p. 479). Earlier, in a letter to *Iron and Coal Trades Review*, (25th March, 1898), Mr. Riley gave an anlysis of the rail, together with that of a typical Blaenavon pig iron, of the type used by Bessemer at his experimental plant at Baxter House, St. Pancras. He reported that the steel had rolled perfectly, but that it broke when hot.

The laboratory of Sandvikens Jernverks AB has carried out a full examination of the section presented to the Company; their report is as follows:

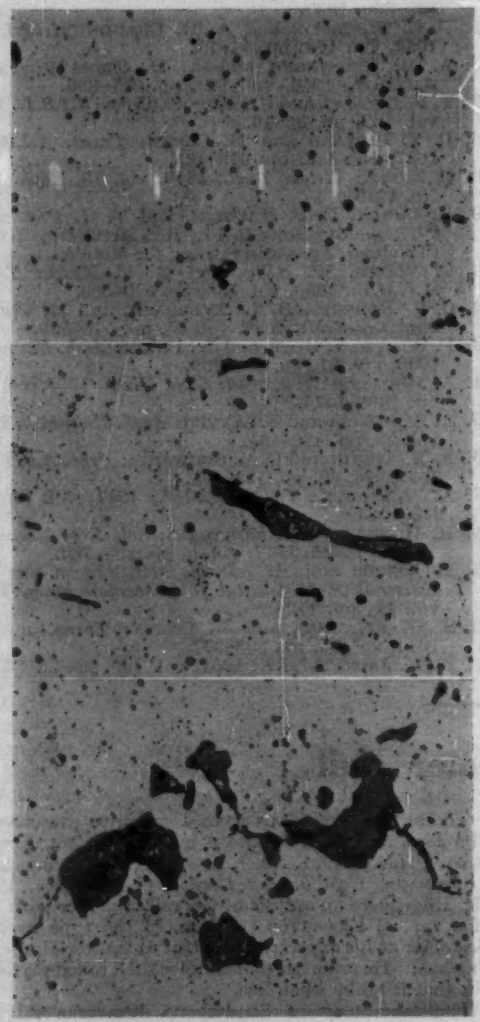


(a) (b) (c)

Fig.1—Rail section: (*a*) etched in Oberhoffer's reagent, to show phosphorus content; (*b*) sulphur print; (*c*) etched in picric acid; the dark areas are due to moisture in the cracks × ½

"A few millimetres were milled from the sample, from the head, web, and foot of the rail, and analysed separately. The analyses are given (on p. 393); those obtained by Mr. Riley are included for comparison. The results of the present investigation confirm those of Mr. Riley.

Figure 1*a* shows the rail section after etching with Oberhoffer's reagent; there is a concentration of phosphorus in the lower part of the web. The sulphur print (Fig. 1*b*) is blackened to an extent rarely seen today. The sulphur seems to be concentrated in the lower part of the rail.



(a)

(b)

(c)

Fig. 2—Photomicrographs of (*a*) head, (*b*) web, and (*c*) foot of rail section × 100

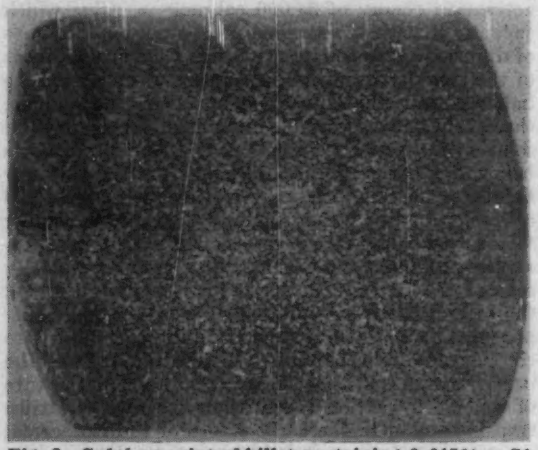


Fig. 3—Sulphur print of billet containing 0·015% × **S1**

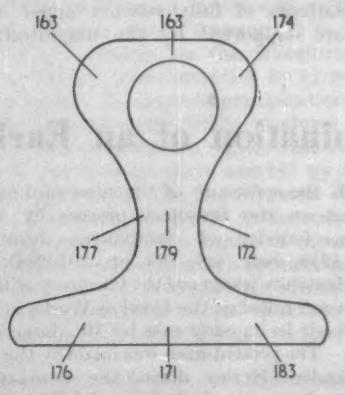


Fig. 4—Hardness survey of rail section (Vickers hardness numbers)

	Blaenavon pig iron 1898	Sample of Bessemer rail			
		Riley 1898	Sandviken 1958		
			Foot	Web	Head
Carbon	3·40	tr.	0·020	...	0·027
Silicon	1·36	tr.	tr.	...	tr.
Manganese	0·20	nil	0·01	...	0·01
Phosphorus	0·29	0·516	0·480	0·520	0·500
Sulphur	0·07	0·235	0·191	0·229	0·190

The sample is very rich in slag, mostly iron sulphide (*see* Figs. 2*a–c*), which have caused cracks and porosity (*see* Figs. 2*c* and 1*c*); Fig. 3 is a sulphur print of a billet containing 0·015% S, which is included for comparison. The hardness of the specimen is relatively low and uniform (Fig. 4). It is obvious that phosphorus and sulphur have been concentrated during the blowing process, even if the 1856 pig iron had higher contents of these elements than those given by Mr. Riley for 1898. It is remarkable that it was possible to roll 'steel' of this composition into a rail."

Powder Metallurgy Joint Group

New Publication

The Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals was formed in 1957 to facilitate the study of the science, technology, and practice of powder metallurgy. Membership of the Group is restricted to members of the two Institutes and already it exceeds 900.

The Group held its inaugural meeting in London on 4th December, 1957, with a symposium on "Developments in the Production and Quality of Metal Powders." This was followed by an informal discussion on 19th March, 1958, on "Developments in the Practice of Compacting and Sintering." There was a large attendance at both of these meetings.

It is intended that the Group shall hold spring and winter meetings each year. The first of these will normally be devoted to an informal discussion on a subject related to the industrial aspects of powder metallurgy, and the second to a symposium or discussion of other papers based on original research.

Originally it was intended that the papers on original work contributed to the meetings of the Joint Group should be published either in the *Journal of The Iron and Steel Institute* or in the *Journal of The Institute of Metals*, according to their subject, and that other papers, such as those contributed to the first two meetings of the Group, would not be published. It has now been agreed, however, by the two Councils that the papers contributed to the first two meetings of the Group are worthy of publication together with summaries of the discussions that took place on them, but that there are important difficulties in the separation of the papers and reports of discussions as between the two journals referred to.

In consequence, the Councils of the two Institutes have now agreed that the papers contributed to the meetings of the Powder Metallurgy Joint Group, together with reports of the discussions on them and all other papers on powder metallurgy offered for publication to either of the two Institutes, shall be printed in a separate publication, which shall initially be published half-yearly, in the spring and autumn. Each issue of this publication will contain the papers to be discussed at the next meeting of the Group, together with a report of the discussion at the previous meeting and other papers on powder metallurgy that may have been accepted for publication. Thus those who receive the new publication can receive, in good time for study, the papers to be discussed at the next Group meeting.

This new publication represents a new departure for both Institutes and a special service for those interested in a branch of metallurgy common to the members of both societies. In view of this, the Councils of the two Institutes have agreed that the annual subscription price to non-members will be 25*s.* post free, with a privileged annual subscription rate of one copy each to members of the two Institutes of 10*s.* post free. Members of the two Institutes who subscribe to the new publication will be regarded as members of the Joint Group for the period of their subscription.

As the decision to issue this new publication has been taken so late in the year and because it is desirable that all the papers so far contributed to the Group proceedings shall be on record in printed form, a double number (1958, Parts 1–2) will be published this year (at the full annual subscription price); thereafter, until further notice, publication will be half-yearly. The Councils of the two Institutes hope that every member now enrolled as a member of the Powder Metallurgy Joint Group will subscribe to the new publication and that many other members who have not yet joined the Group will also take the opportunity to subscribe.

Administration of the Group and editing responsibilities for the publication are undertaken by the staff of The Institute of Metals. All communications regarding the Group and subscriptions to the new publication should be addressed to the Secretary of the Group, Lieut.-Colonel S. C. Guillan, T.D., 17 Belgrave Square, London, S.W.1. Cheques should be made payable to the Powder Metallurgy Joint Group.

A circular regarding this matter, and an order form for the publication, have been despatched to all members of both Institutes and it is hoped that orders for the subscriptions will be promptly received so that the first issue, containing the papers for the Symposium on "The Powder Metallurgy of Ceramic–Metal Materials," to be held at Church House, Great Smith Street, London, S.W.1, on 16th and 17th December, 1958, will be received by subscribers in time for study before the meeting.

Symposium

The next meeting of the Powder Metallurgy Joint Group will be held on Tuesday and Wednesday, 16th and 17th December, 1958, when there will be a Symposium on "The Powder Metallurgy of Ceramic–Metal Materials."

At 6.30 p.m. on Tuesday, 16th December, Dr. P. Murray (Atomic Energy Research Establishment, Harwell) will read an introductory paper. The main part of the Symposium will open at 9.30 a.m. on Wednesday, 17th December, and the meeting will end at about 5 p.m.

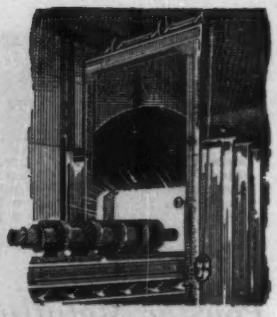
The following papers will be briefly presented and discussed:

J. B. Huffadine, L. Longland, and N. C. Moore: "Fabrication and Properties of Chromium–Alumina and Molybdenum–Chromium–Alumina Cermets"; W. J. Wright, R. B. Gibbon, and J. Williams: "The Fabrication and Properties of Uranium Oxide–Iron Cermets"; R. Kieffer and F. Benesovsky: "Recent Developments in the Field of the Borides and Silicides of High Melting-point Transition Metals"; D. A. Robins: "Bonding in Carbides, Silicides, and Borides"; W. Watt: "The Oxidation of Zirconium Carbide in High-temperature Combustion Gases"; E. Glenny and T. A. Taylor: "The High-temperature Properties of Ceramics and Cermets."

Non-members will be welcome at the meeting and tickets will not be required. Those who wish to take part in the discussion should notify the Secretary of the Group.

IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



A Survey of Forging Manipulators and their Applications

By P. L. Lillywhite, B.Sc. (Eng.)

SYNOPSIS

This paper defines the types of forging manipulator available and describes the products of seven manufacturers. The use of these machines in relation to the layout of various forging plants is also discussed. The Appendix gives details of the designs, with drawings and tabulated data. 1597

INTRODUCTION

WHILE IN THE U.S.A. nearly all forges are fully equipped with mechanical manipulators, the heavy forging industry in the U.K. has only recently begun to show some interest in their use as an aid to higher production. The application of these machines is only part of the larger problem of forge mechanization and the improvement of plant layout, which has arisen from the need for greater production to satisfy the increasing demand for good-quality forgings.

Mechanization of the large number of ingot-handling operations reduces both the fatigue of the operatives and unproductive delays. It should thus be possible to reduce the size of the forging crew and in many cases this is becoming necessary due to the shortage of skilled labour.

The installation of a manipulator in a forge does not automatically guarantee increased production, and improvement is only possible under favourable conditions such as sufficient furnace capacity and suitable plant layout. The duties to be performed must be considered before the type of machine is specified and for heavier forgings the manipulator may have to work in conjunction with a forging crane.

This survey has been carried out to ascertain the types of manipulators available in the U.K. and the duties they are able to perform. At present, they are known to be manufactured in the U.K., the U.S.A., and Germany. The foreign machines are available to firms in the U.K., being either built under licence or imported through agents.

The manipulators are considered under two main headings; rail-mounted and mobile. Details of the various machines are given in the Appendix.

Tool manipulators, or 'hacking' machines as they are sometimes called, have been designed to hold the cutting tools under the press, and because of their contribution to the reduction of manual effort in the forge, they have been included in this survey.

Paper PE/104/56 of the Plant Engineering and Energy Division Panel of the British Iron and Steel Research Association, received on 27th June, 1958. The views expressed are the author's and are not necessarily endorsed by the Panel as a body.

The author is with the Association's Plant Engineering and Energy laboratory, Battersea, London.

RAIL-MOUNTED MANIPULATORS

Rail-mounted machines are usually classified as low, semi-high, or high, according to their capacity and the height of the peel centreline from the floor. The capacity of low machines is usually limited to about 3 tons, greater loads being taken by semi-high and high machines.

All designs may be divided into four groups, according to their travel motions, and these are considered below. Gripping action of the jaws and rotation of the head are motions common to all machines.

Main Types

(1) *Longitudinal-motion (or Straight-line) Manipulator (Fig. 1)*

This is the simplest type of machine and is designed to run on rails in line with the press or hammer. Movement of the trolley is strictly limited to backward or forward motion, all work being transported to and from the press by auxiliary equipment. Provision is sometimes made for skewing the peel in a horizontal plane, thus permitting the use of multi notched die blocks, though aligning with the angled notches is sometimes slow. One design has incorporated a lateral shift of the peel frame to avoid shifting the whole machine when working with parallel notched dies.

(2) *Revolving-trolley, Longitudinal-motion Manipulator (Fig. 2)*

A full-circle rotating motion is now a feature of most designs, giving a much greater freedom of movement at the press or hammer. With this machine it is possible to off-load ingots from conveyors or trucks to the press and dispose of the completed forging.

The increased height of the machine due to the turntable may be compensated by laying the rail track in a pit, below floor level.

(3) *Straight-line Bridge Manipulator* (*Fig.* 3)

The types previously mentioned are limited in their reach when transporting the ingots. The bridge manipulator has a trolley running between the girders of the bridge which travels on rails across the front of the press. With these two perpendicular travel motions the machine is capable of covering a large area and may be used for furnace duties as well as transporting the ingot to the press or hammer. The bridge travel may be used for parallel side shift when working on multi-notched die blocks.

(4) *Revolving-trolley Bridge Manipulator* (*Fig.* 4)

Modern forging-shop layouts usually demand complete freedom of movement for the manipulator. Movements across the front of the press or hammer, travel up and down the shop, and complete rotation are often required. These requirements are satisfied by the revolving-trolley bridge manipulator which, in addition to the two perpendicular motions, can rotate and serve furnaces at right-angles to the press or transport blanks, etc. to any point along the shop. The high structure necessary to accommodate all the motions usually requires a fairly deep pit sunk in the shop floor to bring the peel centreline down to a convenient height.

Motions

Rail-mounted machines have some or all of the following motions:

(i) Jaw gripping	(iv) Trolley rotation
(ii) Peel rotation	(v) Trolley travel
(iii) Parallel hoist and/or peel tilting	(vi) Bridge travel.

(*i*) *Jaw gripping*—The grips are usually pivoted at the ends of cranks which are operated either pneumatically or hydraulically. With the pneumatic system the elasticity of the air in the loaded cylinder is overcome by making the crank-operating mechanism self locking. In the oil hydraulic system, the arrangement of valves and/or accumulator ensures that pressure is maintained while an ingot is gripped in the jaws.

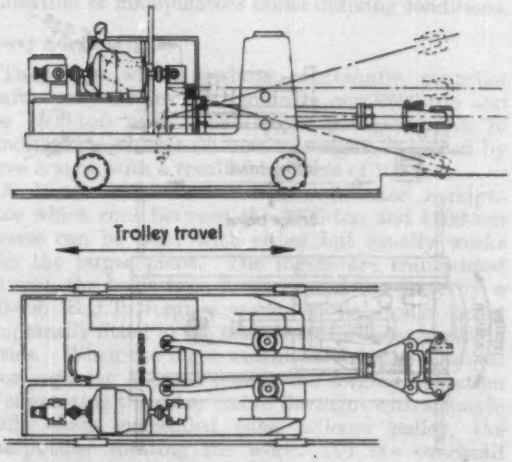


Fig. 1—Simple longitudinal-motion manipulator

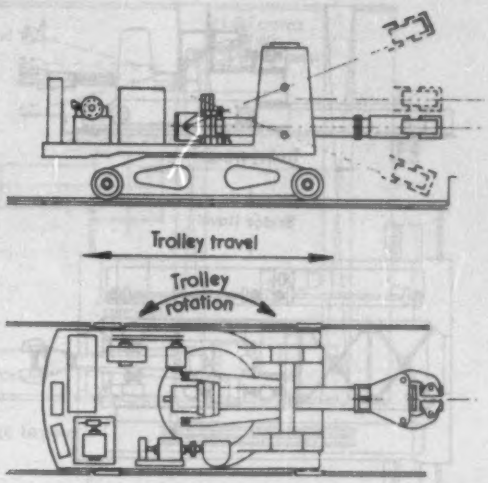


Fig. 2—Revolving-trolley longitudinal-motion manipulator

(*ii*) *Peel rotation*—Full rotation in either direction is actuated by hydraulic or electric motors through reduction gearing. The drive is usually through a torque-limiting device which allows the motor to run while rotation of the ingot is momentarily checked by the press on rapid strokes. This protective device is also needed to take shocks such as those experienced when forging a rectangular-sectioned bloom which is not placed squarely on the anvil.

In some cases a gearbox is used to give more than one speed of rotation.

(*iii*) *Parallel hoist and tilting of the peel*—The hoisting gear varies according to the type and capacity of the machine:

(1) In 'low'-type manipulators hoisting is usually by means of two hydraulic cylinders, mechanically coupled to maintain alignment of the peel. Provision can be made for tilting the peel by operating only one of the cylinders if they are placed fore and aft, or by a separate cylinder at the rear if they are on either side of the peel.

(2) In 'semi-high' machines, hoisting may be by hydraulic cylinders and mechanical linkages or by a cylinder connected to steel wire ropes suspended from pulleys at the top of the machine.

(3) In 'high'-type manipulators the hoisting is usually accomplished by steel wire ropes operated by motors and hoist drums and passing through sprung pulley blocks attached to the peel or peel suspension frame. The rope-operated hoist gives good shock-absorbing characteristics and allows the inclusion of large coil springs in the suspension to accommodate the heavy forging loads.

The levelling motion of the peel in both the 'high' and 'semi-high' types can be obtained by a hydraulic ram, a motor-driven screw and nut, or a rack-and-pinion mounted at the rear of the peel frame.

(*iv*) *Trolley rotation*—The whole of the upper portion revolves in either direction on ball or roller bearings. A slipping clutch is provided in the geared

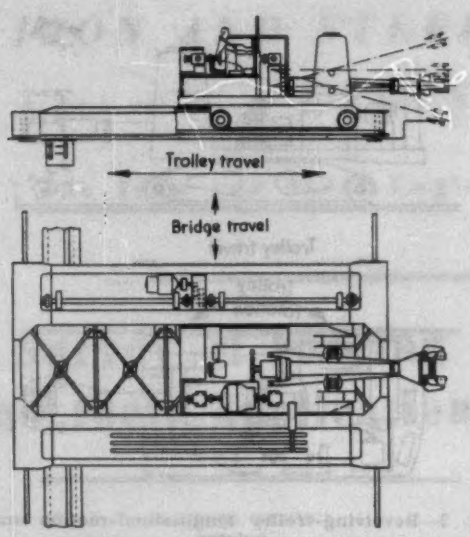


Fig. 3—Straight-line bridge manipulator

worm drive so that contact between the trolley and external obstructions does not damage the driving motor.

(*v*) *and* (*vi*) *Trolley and bridge travel:*—The drives for these motions are usually the same as on normal rail-mounted machines, the track wheels being driven through reduction gearing by electric motors. However, some designs use hydraulic rams, either acting directly on the machine frame or actuating a rack-and-pinion drive to the wheels.

MOBILE MANIPULATORS

There is only one basic type of mobile manipulator, although the peel suspension units may vary in detail. These machines may have an electric motor as the prime mover, with a spring-loaded take-up reel for the cable, or they may be self-contained with a diesel engine supplying all the power requirements.

The pump motors and auxiliaries are mounted on the main chassis which has two front wheels and is both driven and steered by a single central wheel assembly at the rear.

The peel frame is supported in the chassis by a system of connected crank levers actuated by hydraulic cylinders. The lever system maintains a parallel lifting motion or, by controlled movement of the lever pivots, enables the peel to be tilted, this being necessary when picking up ingots from the floor. The head rotates continuously in either direction and the jaw-gripping motion is usually actuated hydraulically by a cylinder mounted at the rear of the peel. A limited amount of side shift is sometimes provided on the peel frame to allow quicker lining up of the ingot.

The whole system is cushioned mechanically and hydraulically against the shock loads experienced during forging.

TOOL MANIPULATORS

Tool manipulators, or 'hacking' machines are specially designed to hold the cutting tool under the press. They eliminate the laborious manhandling of heavy and unwieldy cutting tools, thus reducing the cutting-off operation to a quick and simple process.

The machines are not standard since they have to be designed to suit the particular application but the basic requirements are the same. The tool holder moves in vertical slides, the stroke being restricted by the movement of the press crosshead. The supporting framework may be rail-mounted or fixed. In the former case the tool is moved into the press by driving the whole frame forward, whereas with the fixed frame, longitudinal motion of the tool is operated by a hydraulic cylinder mounted on the body of the lifting trolley.

MANIPULATOR DUTIES

Although standard types of manipulators are manufactured, the number, range, and speed of the motions provided must depend on the user's specification. The type of machine, i.e. mobile or one of the rail-bound models, will depend on both the layout of the plant and the duties to be performed.

The carrying capacity is the first consideration since mobile manipulators are at present limited to about 12-tons capacity. Above this figure only rail-bound machines can be considered. At very high capacities the number of travel motions on a rail-mounted manipulator is restricted and the machine tends towards the simplest type.

The layout of the plant has to be considered next. The distance from furnace to press and the method to be adopted for bringing the ingot to the press and disposing of it after forging will determine the travel motions required on the manipulator and the auxiliary plant necessary. The available floor space is naturally an important factor, especially when a mobile manipulator is also used for furnace duties and has to be manœuvred between furnaces and the press or hammer.

The type of forging and method of forming will decide the motions required. In axle forging, lining-up the bloom with the multi-grooved swage tool may take longer with a mobile manipulator which

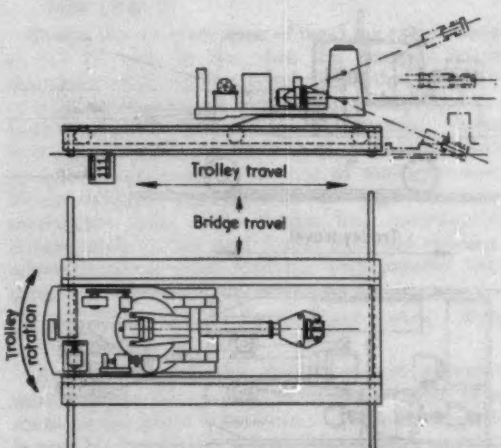


Fig. 4—Revolving-trolley bridge manipulator

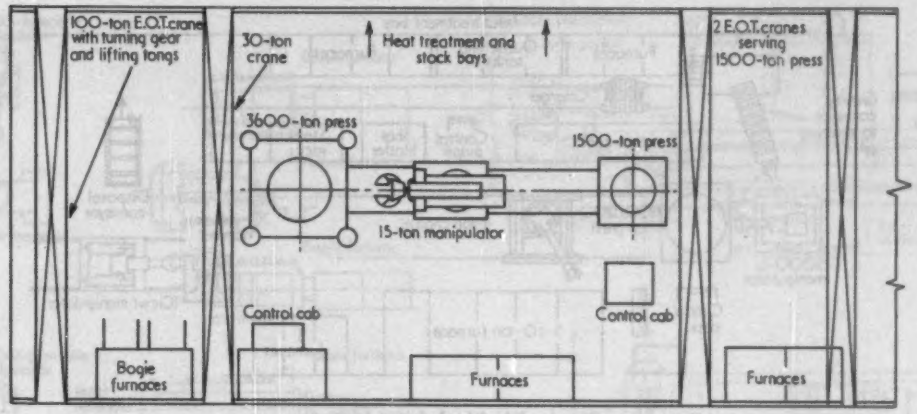


Fig. 5—Heavy forge layout

has to be manœuvred into position whereas the rail-bound machine is easily lined up with the press or hammer. If a mobile machine is working on parallel-grooved swage tools, this difficulty may be overcome by using a manipulator with lateral shift.

There has been a tendency to use mobile manipulators for all ingot-handling duties in the forge, including furnace charging. This is usually economical only if the furnace capacity is insufficient to maintain a constant supply to the forge and the manipulator would otherwise be idle. A mobile machine intended for such duties should incorporate a rocking hoist motion for picking up work from floor level, though this is usually standard in current designs.

Although almost as flexible as mobile machines, the bridge-type rail-bound manipulators usually have the peel too high for normal operations and may have to run in a pit which is deep enough to bring the peel down to the level of the anvil.

DESCRIPTIONS OF TYPICAL INSTALLATIONS

The forges described have been chosen to illustrate the various types of layout in the U.K. and the utilization of manipulators under differing conditions.

Heavy Forge (Fig. 5)

This forge, which produces crankshafts, propellor shafts, rotor bodies etc., contains one 3600-ton and one 1500-ton press. The larger plant, capable of handling ingots over 60 tons in weight, is served by three cranes, with a total lifting force of 100 tons.

A 15-ton rail-bound Adamson-Alliance manipulator which runs between the 3600-ton and 1500-ton presses can be used with either but usually works with the larger plant. The ingots are transported between the bogie-type furnaces and the press by a 100-ton E.O.T. forging crane, special tongs being temporarily fitted to the main hoist for these handling duties. When the ingot weight exceeds the manipulator capacity a crane assists the forging operation by supporting the other end of the ingot with a simple bridle chain suspended from a loose pulley, the manipulator rotating the work. All the overhead cranes are controlled from the ground, the drivers being either side of the press operator in the control pulpit.

The 15-ton manipulator is a high, revolving-trolley straight-line type with a rope-and-pulley hoist. The driver is at the front of the machine, but is on the side further from the control pulpit when working with the 3600-ton press. This means that, although he has a good view of the ingot, he has difficulty in seeing the press and crane operators and must rely on the leader of the forging team for signals.

Die Block and Small-section Forge (Fig. 6)

The main part of the forge contains the plant for producing die blocks. This consists of a 600–1200-ton air intensifier water hydraulic press and a 5000-lb rail-mounted manipulator fed by a Wellman 4-ton bridge charger.

The blocks mainly vary in weight from 4 to 12 cwt but sometimes reach 2 tons. They are heated in five 10-ton oil-fired furnaces, though only three are in service at once. The blocks are taken from the furnace to the anvil of the press by the charger which runs on rails in front of the five furnaces. The furnace system includes automatic door control whereby the driver can operate the door from his machine by push-button, electrical contact being made through separate rail sections situated under the floor opposite each furnace.

When the die-block has been upset and forged it is placed on a gravity conveyor by the manipulator and travels into the cooling and trimming pit. The forgings then pass into the heat-treatment bay which is at a lower level. The Alliance manipulator, supplied by the U.S. company, is a low, straight-line revolving type with only a tilting motion of the peel. The machine is well suited to the die-block work but is limited in operation when handling the long blooms which are sometimes forged.

At one end of the forge are three small furnaces serving a 30-cwt C-frame air hammer. A 10-cwt Wellman-Smith-Owen low, straight-line manipulator (the only rail-mounted machine produced by this company) handles blooms up to 10 in. x 10 in. A fork-lift truck with charger attachment takes the blooms from the furnaces to the hammer and disposal

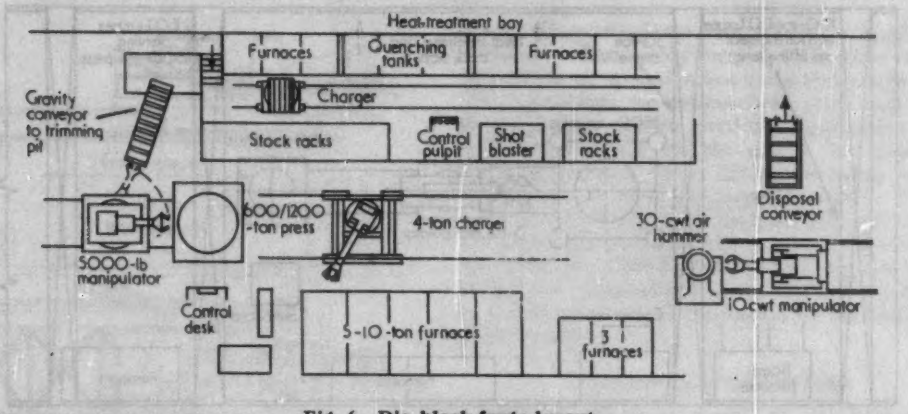


Fig. 6—Die-block forge layout

of the forging is effected by a floor-level gravity conveyor which feeds the heat-treatment bay.

Mechanized Railway-axle Forge (Fig. 7)

The axle forge comprises a 10-ton electric overhead magnet crane, a continuous gas-fired furnace, a rail-mounted manipulator, a 7-ton steam hammer, a heat-treatment furnace with quenching tank, a cold straightening press, and end saws with an inspection line at the end.

The layout of the original plant was the best available to suit the conditions and requirements at the time. A scale breaker and delivery and return conveyor systems are later additions to reduce unproductive handling by the manipulator. As is often the case, the forge layout is necessarily a compromise. Considerable simplification and improvement could be made in a design for a layout having no limitations on space or siting of the plant.

The rail wagons carrying the axle blooms are run into the bay where the 10-ton crane unloads the blooms and stacks them next to the pusher-type continuous furnaces. After heating for 5 h, a pusher delivers the bloom at right-angles to the furnace centre-line on to gravity rollers via a scale breaker. The roller conveyor then takes the bloom to the side of the tool, under the hammer leg, within easy reach of the manipulator.

Throughout the forging process all handling is done by the 6000-lb Adamson-Alliance manipulator of the rail-mounted, straight-line bridge type, running on a track laid in a pit across the front of the hammer. When one end of the bloom has been forged, it has to be turned through 180° to grip the other end. This is facilitated by a hydraulically operated turntable mounted on the front of the manipulator and controlled by the driver. A safety-glass screen protects the driver from flying scale, his position at the front of the manipulator allowing a good view of the forging, though he is not in a good position to see the hammer operator.

Forging is carried out by a 7-ton Massey steam hammer with a working pressure of 90 lb/in². Normal hand-lever controls are fitted to the hammer, and jets of water can be played on the bloom during forging to ensure the removal of all scale and give a good

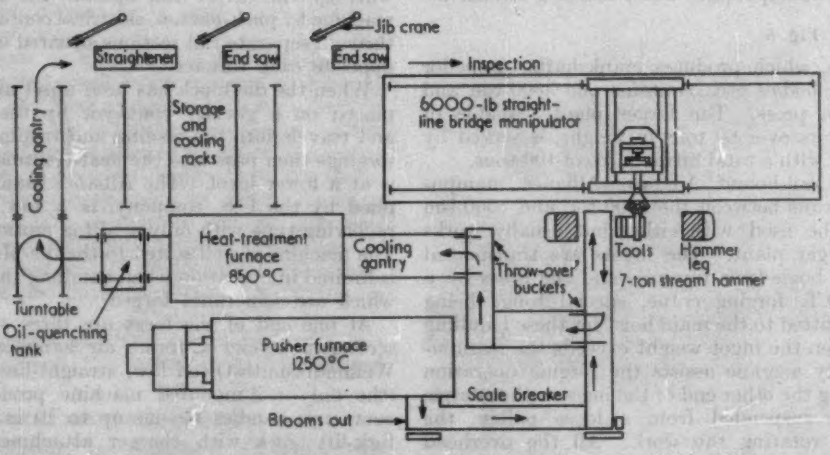


Fig. 7—Mechanized axle forge

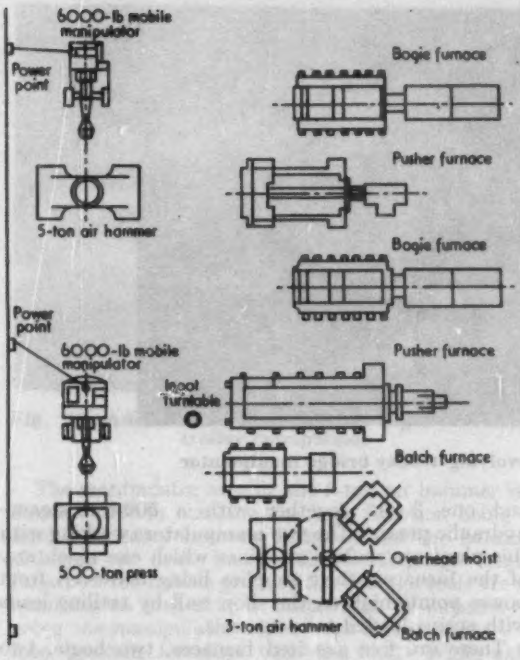


Fig. 8—Forging plant for axles and special steels

finish to the forging. Double-grooved fixed swage tools are used, one groove for the middle of the axle and the other for shaping the end collar, journal, and wheel seat. When forging is completed, the manipulator sets the axle down on the roller table under the hammer leg and picks up the next bloom which has been delivered to the same point.

The completed axle is then carried, via a 'throw-over' bucket and separate conveyor system, to the forehearth of the heat treatment furnace. The axles roll down the sloping hearth of the furnace and in four hours' heating are raised to 850° C before being discharged on to a platform above the quenching tank. Those for normalizing pass straight across

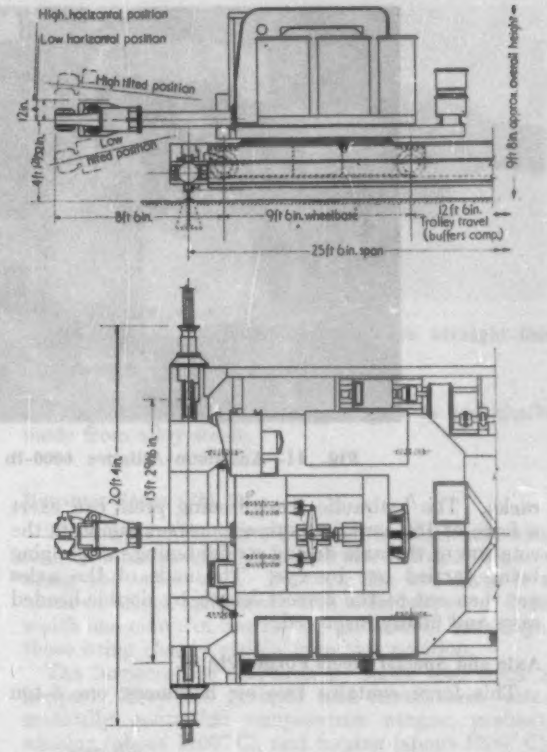


Fig. 10—Adamson-Alliance 6000-lb straight-line bridge manipulator

on to a turntable and then to cooling racks. The axles to be quenched are retained on the platform by stirrups and lowered into the tank where the oil temperature is controlled within certain limits by coolers. The axles are then raised and rolled on to the turntable from which they are fed to cooling

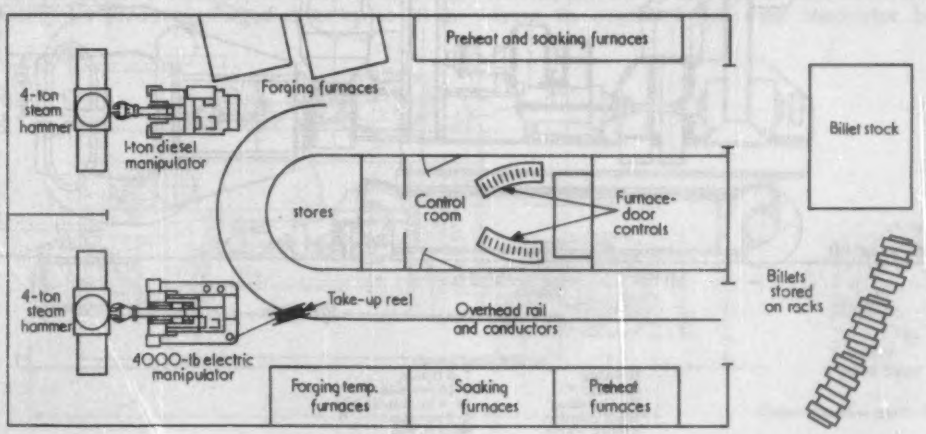


Fig. 9—Hammer-forge layout

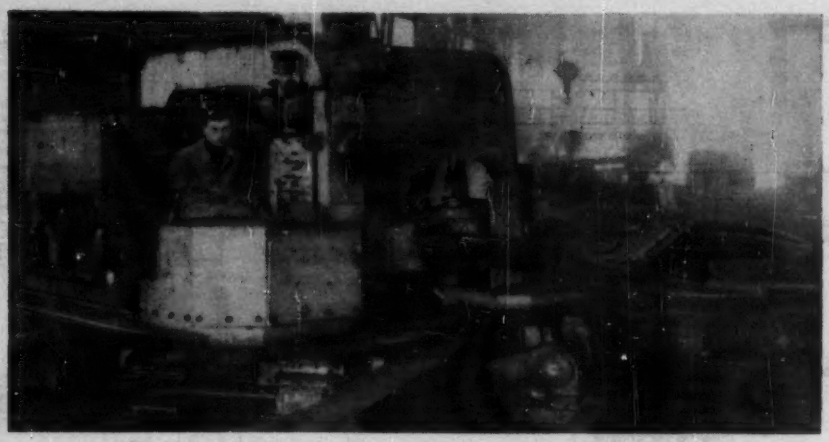


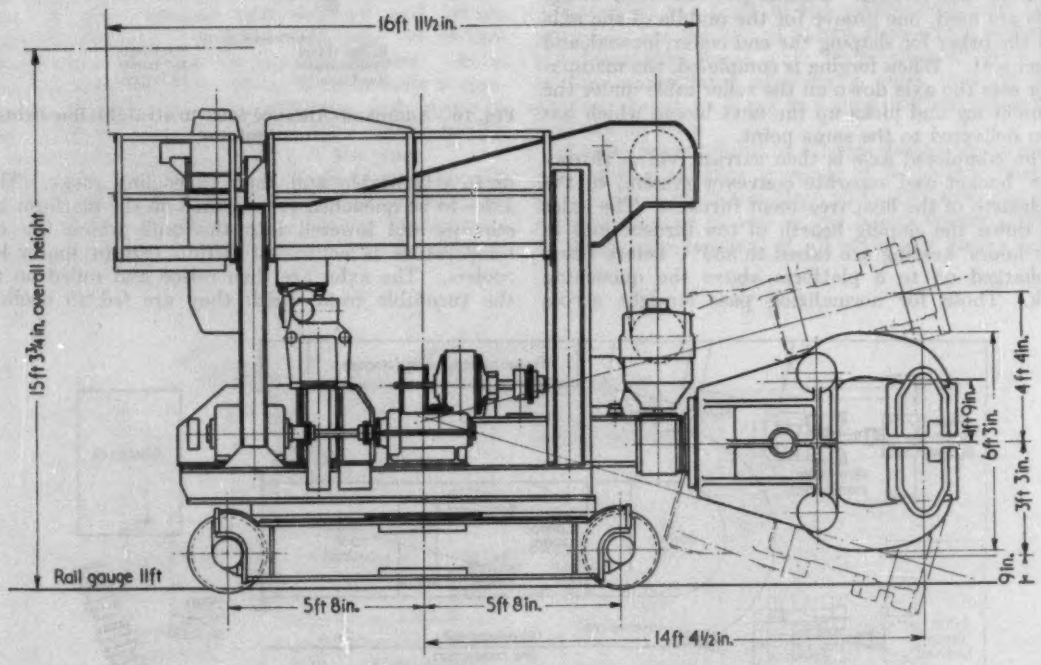
Fig. 11—Adamson-Alliance 6000-lb revolving-trolley bridge manipulator

racks. The hydraulic straightening press can exert a force of 150 tons and spinning rollers facilitate the rotation of the axle during straightening, all gauging being carried out by eye. The ends of the axles are then cut to the correct length by double-headed saws and finally inspected.

Axle and Special Steels Forge (Fig. 5)

This forge contains two air hammers, one 5-ton and one 3-ton, together with a 500-ton steam–hydraulic press. The two manipulators working with this plant are mobile machines which can reach any of the furnaces, their supplies being delivered from power points high on the shop wall by trailing leads with spring-loaded take-up reels.

There are five gas-fired furnaces, two bogie, two pusher, and one batch, all feeding either the 5-ton hammer or the 500-ton press.



Estimated Speeds	
Hoisting	7·3 ft/min
Slewing	3·16 rev/min
Peel levelling	25·8 in./min at bits
Head rotation	7·1 rev/min
Trolley travel	66·0 ft/min

Fig. 12—Adamson-Alliance 15-ton high revolving-trolley manipulator

Fig. 13—Adamson-Alliance 15-ton high revolving-trolley manipulator

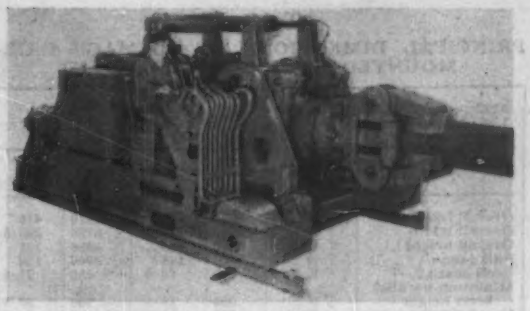


Fig. 14—Dango and Dienenthal 2·5-ton straight-line manipulator

The manipulator serving the 5-ton air hammer is a Brosius 6000-lb machine, its main function being to fetch and carry between furnaces and the hammer although it does handle simple forgings. Axles forged on the double-grooved fixed swage tools are all manhandled and this is claimed to be superior to using the manipulator which loses time manœuvring into position to align with the tool. While axles are being forged the manipulator usually works at the furnaces, transferring blooms and turning them over.

The 500-ton press is served by a Wellman-Smith-Owen 6000-lb mobile manipulator which, besides fetching the bloom from the furnace, also holds it under the press during forging. A turntable, near the furnaces, is used to turn the bloom round when one end has been forged.

The flexibility of the system in this forge is suited to the varying nature of work carried out. A large amount of high-alloy steel is handled and the 'saddening heats', together with the limited range of forging temperatures, necessitate a great amount of handling between furnaces and press or hammer. The manipulators are thus constantly at work even though they may not be engaged in the actual forging operation.

To one side of the furnaces is the 3-ton air hammer used mainly for producing forged rings up to 30 in. dia. and various types of forged spindles and shafts made from alloy steels.

Hammer Forge (Fig. 9).

The forge contains two bays side by side, each with its own 4-ton steam hammer at one end and furnaces along the outer wall. Between the two bays is a block of offices and stores with a central room from which one man can control the furnaces in both bays, these being clearly visible from this position.

The furnaces are coal-fired by screw feed from a hopper. They are grouped and cover three automatically controlled temperature ranges; preheat, soaking (about 1100° C), and forging (about 1250° C). Their doors are operated, in one bay hydraulically and the other pneumatically, from the control room, signals being given by the manipulator drivers when they require the doors to be opened for charging or withdrawing ingots.

There are two mobile Wellman-Smith-Owen manipulators in the forge, one in each bay. Both are used for all ingot handling including furnace charging.

The first machine, of 4000-lb capacity, has been in use since 1946 and was the first British mobile manipulator to be built after the war. The electric power for this machine is supplied by a cable which uncoils from a spring-loaded collector reel suspended from an overhead rail with conductor bars. This

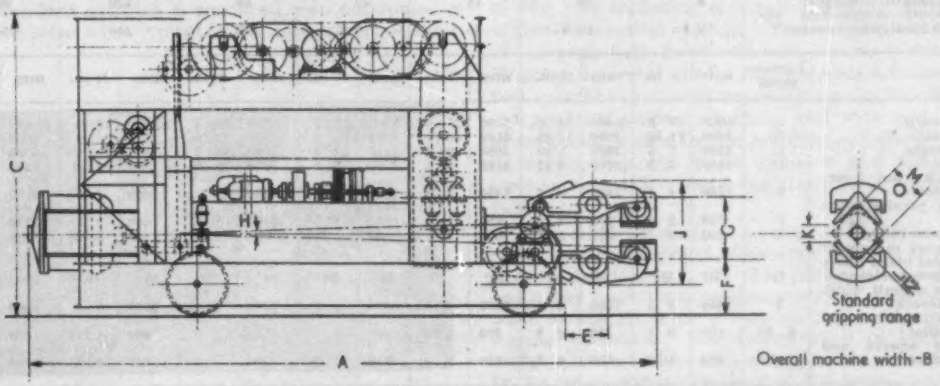


Fig. 15—Demag straight-line manipulator

Table I

PRINCIPAL DIMENSIONS OF 'DEMAG' RAIL-MOUNTED MANIPULATORS (Fig. 15)

M/C capacity, metric tons		5		12·5	
Unladen weight, metric tons		61		97	
	Dimensions	mm	in.	mm	in.
Overall length	A	8320	328	10570	416
Overall width	B	5570	219	5700	223·5
Overall height	C	4400	173	4850	191
Rail gauge	D	3700	145	3900	154
Head reach	E	480	19·0	650	25·6
Minimum parallel hoist height	F	750	29·5	960	37·7
Parallel hoist range	G	800	31·5	700	27·5
Angular peel movement:					
In vertical plane	H°	3°	3°	3°	3
In horizontal plane	I°	8°	8°	8°	8°
Maximum overall width of grip levers	J	1300	51	1600	63
Maximum jaw opening	K	400	15·7	480	19·0
Minimum square billet	L	220	8·7	440	17·3
Maximum square billet	M	650	25·6	900	35·4
Minimum round billet	N	220	8·7	440	17·3
Maximum round billet	O	650	25·6	900	35·4

Capacity of 5-ton machine is based on an ingot length of 6·5 m (21·3 ft)
Capacity of 12·5-ton machine is based on an ingot length of 8 m (26·3 ft)

overhead system runs the length of one bay and round into the adjacent section, enabling the manipulator to reach both hammers and also to run out of the end of the bay to the stockyard. Since this machine has only a parallel hoist motion and no provision for tilting the head to ground level, the ingots in the stockyard are stored on racks at a convenient height for the manipulator to pick them up.

The driver's position at the rear of the machine on the left-hand side restricts his view of the right-hand side of the head and jaws. A large mirror has therefore been fitted on the off-side of the manipulator in such a position that the driver has a clear view of both sides of the head, this being essential when handling ingots at the furnace.

Fig. 16—Demag 12·5-ton straight-line manipulator

The hammer with which the 4000-lb machine works is engaged exclusively on the cogging of special steels which require a large number of reheats owing to their limited forging-temperature range. The smaller sizes of ingots (about 9 in. × 9 in.) are more easily forged with hand manipulation, and the usual procedure is to use the manipulator in the initial stages to reduce large ingots, then part off the smaller section for manual forging, the remainder being returned to the furnace for reheating.

The second machine is a 1-ton capacity diesel-powered manipulator. This is employed with the jobbing hammer and is more suited to this work since the mechanism incorporates a rocking hoist which tilts the head. The manipulator can therefore pick up ingots or tools and dies from the floor, thus assisting the crew in the heavier handling jobs.

CONCLUSIONS

A wide range of capacities and types of manipulator is now available to suit most forges. A careful

Table II

PRINCIPAL DIMENSIONS OF 'HYDRAULIK' RAIL-MOUNTED MANIPULATORS (Fig. 17)

M/C capacity, metric tons		2·5		4		7·5		15		25		40		100	
Maximum billet length, metres		4		5		4·8		5·3		4·8		6		8	
Unladen weight, metric tons		18		32		55		85		140		180		530	
M/C capacity, metre-tons rating (½ Billet length — weight)		5		10		18		40		60		120		400	
M/C capacity—metre-tons referred to front-wheel centre *		8·1		15·6		33		75·8		135		256		750	
	Dimensions	mm	ft in.	mm	ft in.	mm	ft in.	mm	ft in.	mm	ft in.	mm	ft in.	mm	ft in.
Overall length	A	6000	19 8	6400	21 0	7750	25 5	9200	30 2	10,800	35 5	12,200	40 0	18,550	60 10
Overall width	B	3600	11 10	3900	12 10	5150	16 11	5700	18 9	6700	22 0	7700	23 4	6600	21 8
Overall height	C	2200	7 3	2400	7 10	2850	9 4	3150	10 4	4000	13 2	4800	15 9	8500	27 11
Rail gauge	D	1450	4 9	1800	5 11	2180	7 2	2600	8 6	3300	10 10	3800	12 6	5200	17 1
Head reach from front-wheel centre	E	1250	4 1	1400	4 7	1450	4 9	1800	5 11	2200	7 2½	2400	7 10½	2500	8 2½
Minimum parallel hoist height	F	700	2 4	700	2 4	850	2 9	1000	3 3	1200	3 11	1400	4 7	2235	7 4
Parallel hoist range	G	400	1 3½	500	1 7½	600	1 11½	600	1 11½	800	2 7½	1000	3 3½	1500	4 11
Angular peel movement in vertical plane above and below horizontal	H°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°	10°
Maximum overall width of grip levers	J	1050	3 5	1250	4 1	1550	5 1	1950	6 5	2300	7 6	2500	8 2	3600	11 10
Minimum square and round billet	K, M	180	0 7	230	0 9	270	0 10½	400	1 3½	620	2 0½	600	1 11½	840	2 9½
Maximum square and round billet	L, N	425	1 5	500	1 7½	620	2 0½	850	2 9	1300	4 3	1300	4 3	1700	5 7

* Some manufacturers specify M/C capacity as the product of ingot weight and distance between c.g. of ingot and front-wheel centre. This figure has also been included in the above table for comparison with other machines

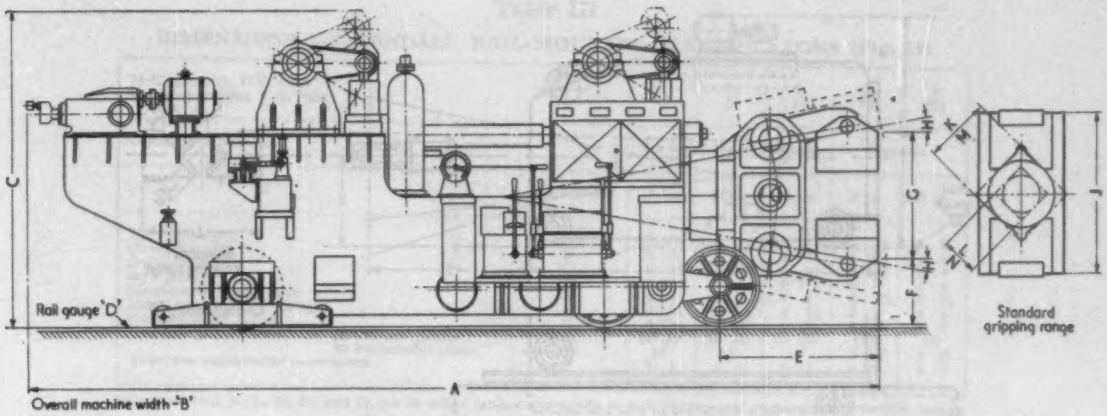


Fig. 17—Hydraulik straight-line manipulator

appraisal of the merits of each design is necessary before making a final choice, particularly in relation to modifications and other improvements in forge layout which may be found desirable at a later stage.

Acknowledgments

The author acknowledges with thanks the considerable assistance given by the manufacturers, listed below, who have supplied the data and drawings for this report:

Adamson-Alliance Co., Ltd., The Head-Wrightson Machine Co., Ltd., The Wellman-Smith-Owen Engineering Corporation, Kendall Contracting Inc. (U.S.A.), The Wellman Engineering Company (U.S.A.), Dango and Dienenthal KG (Germany), Demag AG (Germany), Hydraulik G.m.b.H. (Germany).

Thanks are also due to the following companies by whose kind permission the forge layouts are reproduced: Brown Bayley Steels Ltd., Daniel Doncaster and Sons, Steel Peech and Tozer, Walter Somers Ltd.

Figure 13 is reproduced by permission of Thos. Firth and John Brown Ltd., Sheffield.

APPENDIX

Details of Rail-mounted, Mobile, and Tool Manipulators

The appendix deals with the designs of the various manipulator manufacturers, includes drawings of the machines, and tables of the main dimensions.

Rail-mounted Manipulators

Adamson-Alliance Co., Ltd. (*U.K.*)—This company builds various types embodying basic features of U.S. design, with other features developed to meet the requirements of U.K. and Continental forge practice. Manipulators up to 15-tons capacity have been built. The actual design depends on the customer's requirements and, as no standard machine is produced, two manipulators have been selected as typical of the different types available.

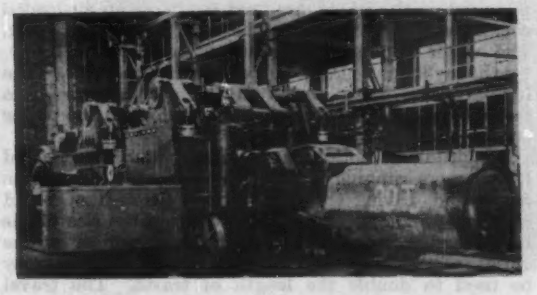


Fig. 18—Hydraulik 20-ton straight-line manipulator

The first of these two machines is the 6000-lb straight-line semi-high bridge manipulator (Fig. 10). A similar machine with a revolving trolley is shown in Fig. 11. The peel is suspended at the front by wire ropes which pass over pulleys to a yoke and crosshead attached to a horizontally disposed hydraulic cylinder in the top of the trolley. The ropes are attached to the front of the peel via double vertical compression springs to absorb forging shocks. The rear of the peel is supported by a vertical hydraulic cylinder suspended from the rear of the upper trolley frame, the cylinder fixing on the end of the peel including a shock-absorbing arrangement of three horizontal springs. Vertical guides at the sides of the peel, both front and rear, ensure a straight lift. Hoisting is carried out by simultaneous actuation of the two cylinders and levelling or tilting can be effected by independent control of front and rear cylinders. A single pump is used for the levelling cylinder and a dual pump supplies the hoist cylinder and the gripping mechanism. Oil pressure for the system is about 1000 lb/in^2.

The peel is rotated by an electric motor, a slipping clutch being interposed to prevent damage to the drive due to overloading. In this particular machine the end of the ingot bears against a sprung plate in the tong head to absorb some of the shocks incidental to the forging operation. The trolley runs in between the bridge girders, in line with the press or hammer and the bridge travel across the front of the press provides side shift.

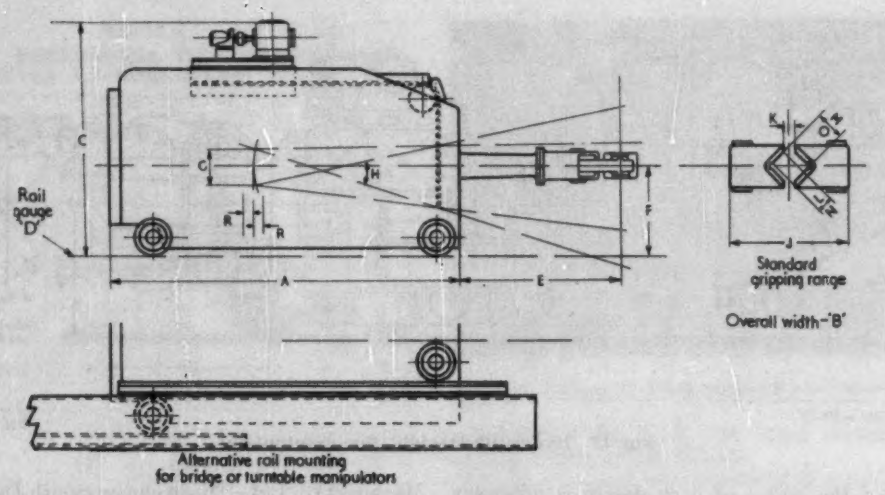


Fig. 19—Kendall straight-line manipulator

The second machine is a 15-ton high revolving-trolley manipulator (Figs. 12 and 13). Rotation of the upper frame on the trolley is operated by an electric motor driving through a worm reduction and spur gearing mounted on the base of the main frame. The front of the peel is supported by a wire-rope pulley system, the lower pulley block assemblies incorporating heavy compression springs to absorb vertical forging loads. The ends of the suspension ropes are wound on to electrically driven hoisting drums situated at the rear, on the top of the upper trolley frame. Suspended under this frame is the peel-levelling gear consisting of vertical side guides with an electrically driven screw-and-nut hoist attached to the rear of the peel frame. The front of the trolley frame has vertical guides for lateral alignment of the peel during vertical movement. The geared turning-motor assembly, with slipping clutch, is mounted on top of the peel frame and the double-acting hydraulic gripping cylinder is fitted at the rear. Shock loadings in the line of the peel are absorbed by spring buffers at the back of the frame. The electric power for the pump unit and driving motors is picked up from conductor rails under the floor.

Alliance Machine Co. (U.S.A.)—This company builds all types of rail-mounted manipulators up to 75 U.S. tons capacity. Similar machines are available to British firms. These are built by the Adamson-Alliance Company of Great Britain as described.

Dango and Dienenthal K.G. (Germany)—Hydraulically operated straight-line machines up to 5 metric-tons capacity have recently been introduced by this firm which originally produced mobile manipulators only. The peel is raised by a double crank lever system, the front and rear pairs being linked by double-acting cylinders to facilitate levelling. Details of the manipulators are not yet available. The 2·5-ton machine is shown in Fig. 14.

Demag A.G. (Germany)—These manipulators are electrically driven straight-line machines with front-wheel drive, giving a travel speed of about 150 ft/min. The peel is sprung horizontally and vertically by buffer springs within a frame which is suspended at the front by steel wire ropes and at the rear by a rack assembly. Two sets of vertical guides at the front of the machine ensure vertical lift, one between the peel and its supporting frame and the other between this frame and the machine main structure. Parallel hoist is effected by a motor driving the rope drum and rack simultaneously through a reduction gearbox, the hoist speed reaching 200 in./s. The peel may be tilted 3° by driving the rack separately with an additional motor and provision is made for skewing 8° in the horizontal plane.

On the latest machines any one of four speeds: 4, 7, 11, and 15 rev/min may be selected for griphead rotation. The drive is provided by two motors of different rating connected through an epicyclic gear. Jaw gripping is controlled by a pneumatic cylinder at the rear of the peel. The working pressure for the air is 6–8 atm and the supply is taken from suitable external sources such as the works compressed-air system. Receivers are mounted on the manipulator to reduce pressure variations.

The range of capacities manufactured extends from 5 to 20 metric tons and details of the 5- and 12·5-ton machines are given in Table I and Fig. 15. The 12·5-ton model is shown in Fig. 16.

Hydraulik G.m.b.H. (Germany)—Only straight-line manipulators are manufactured by this company which departs from normal practice by using pressurized water to effect all the motions. The low machine frame is of double-walled welded construction with transverse stiffeners, the hollow frame serving as a storage tank for the water.

Electrically driven, enclosed triple-plunger pumps, mounted on the frame, are used to charge an air-loaded accumulator system from the built-in storage tank. The water is then distributed, at about 1500 lb/in^2, to the cylinders via the operator's valve gear. The high-pressure water stored in the accumulator gives fast movements without large fluctuations in the power consumption.

Longitudinal motion of the manipulator is effected by plungers running in two cylinders on the machine frame and driving the main wheels through a geared rack-and-pinion system. Depending on the size of the machine, the travel for the complete plunger stroke varies from 23 to 59 ft, though a clutch arrangement may be used to double the length of travel. The travel speeds are 160 ft/min and 100 ft/min respectively.

Table III

DIMENSIONS OF KENDALL RAIL-MOUNTED MANIPULATORS (Fig. 19)

M/C capacity, U.S. tons		1	1½	2	5	6
Unladen weight, U.S. tons		10	10	10	30	37½
Operator's location		On Machine or Remote			Remote	
	Dimensions	ft in.	ft in.	ft in.	ft in.	ft in.
Trolley length	A	8 7½	8 7½	8 7½	14 2½	15 5
Overall width	B	5 6	5 6	5 6	8 11	9 3
Overall height	C	6 0½	6 0½	6 0½	8 3½	8 9
Rail gauge	D	5 11½	5 11½	5 11½	6 6	6 6
Maximum head reach	E	4 6	4 6	4 6	4 7½	5 7½
Mean parallel hoist height	F	2 2½	2 2½	2 2½	2 6	2 6
Parallel hoist range	G	0 10½	0 10½	0 10½	0 9	0 9
Angular peel movement: In vertical plane	H°	30° 30′	30° 30′	30° 30′	19°	19°
In horizontal plane	I°	14°	14°	14°	9° 30′	9° 30
Traverse accelerator movement	P	0 3	0 3	0 3	0 8	0 8

Dimensions J, K, L, M, N, and O, (as in other tables) are made to suit customers' requirements within reason

The two main horizontal supporting shafts, mounted across the frame of the machine, are each provided with two cranks connected to the lifting cylinders mounted vertically on both sides of the machine. Rocking levers, also attached to each shaft, support the peel by four vertical rods suspended in spherical bearings. The peel is thus free to give in all directions, shocks being absorbed by pneumatic buffers and rubber cushions in the suspension rods. Parallel hoist is achieved by feeding the main cylinders simultaneously and the peel may be tilted by operating only the rear or front pair of cylinders separately. A parallel or inclined hoist speed of 8 in./s may be attained. Although earlier designs incorporated side shift, this has been discontinued on the standard models.

The jaws are rotated by plungers, the angle turned through at each operation being limited to 400° by the plunger stroke. However, if continuous rotation is required, a reversing gear may be operated by the driver or actuated automatically at the end of each stroke. The rotation is momentarily stopped after each movement and this makes a protective slipping clutch arrangement unnecessary for such operation as planishing while rotating the ingot. The intermittent rotational speed is 15 rev/min on the smaller machines, down to 10 rev/min on the largest. The speeds for continuous rotation are about half these values.

The driver's position, which may be either side at the front of the machine, is arranged to face inwards, so that the ingot is always to one side of the operator. Electrical power is supplied via either a cable and take-up reel or conductor rails under the floor.

The manufacturers are able to supply machines up to 100 metric-tons capacity. Details of the standard manipulators, from 2·5 to 40 metric-tons capacity, and the large 100-ton machine are given in Table II and Fig. 17. The 20-ton manipulator is shown in Fig. 18.

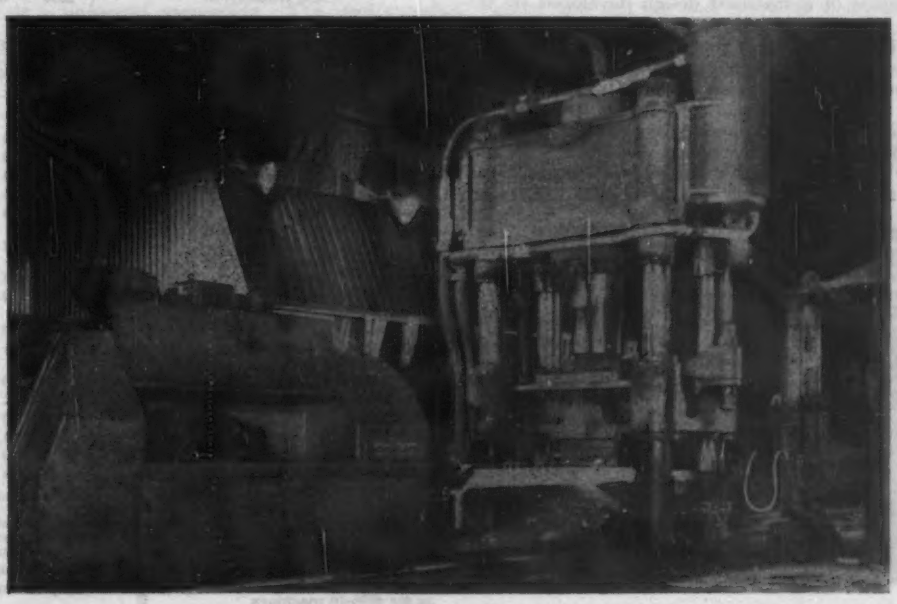
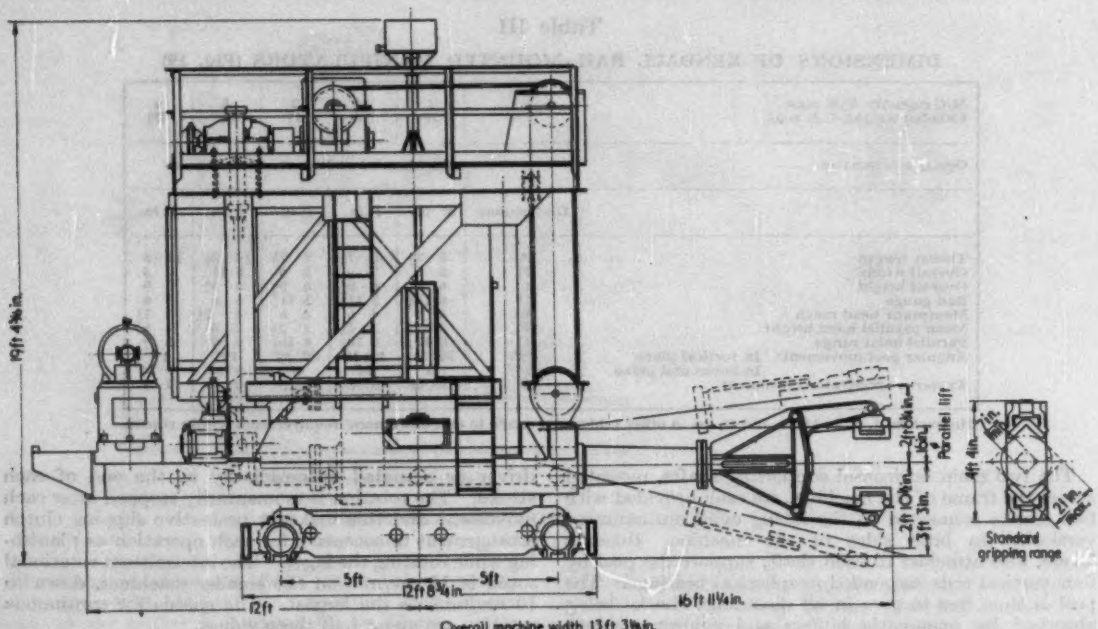


Fig. 20—Kendall 10,000-lb remote-controlled straight-line manipulator



Estimated Speeds

Trolley travel	112 ft/min
Trolley rotation	4 rev/min
Hoisting	16 ft/min at bits
Head rotation	12 rev/min
Jaw gripping time (full range)	6 s

Fig. 21—Wellman 10,000-lb high revolving-trolley manipulator

Kendall Contracting Incorporated (U.S.A.)—This company is concerned with complete schemes for forge layouts and as a consultative organization has developed rail-mounted manipulator designs to suit particular applications to forging units. Although the manipulator trolley is of a standard design developed by the company, the travel motions supplied are extremely varied. Machines are designed with any of the four main types of motion and in addition the rail track assembly may be mounted on its own turntable and, if necessary, provided with a limited amount of side shift.

Manipulators mounted on a bridge or turntable have two trolley travel rails per side. The front wheels of the trolley run on one pair of rails mounted on the top flange of the main girders, while the rear wheels are

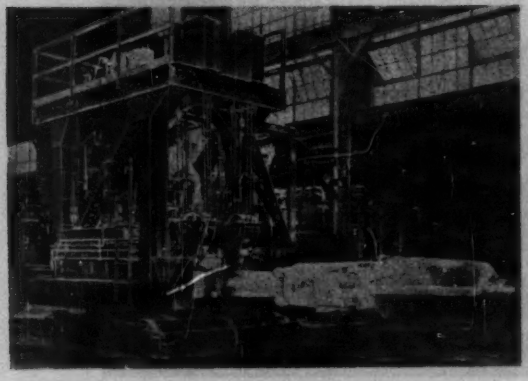


Fig. 22—Wellman 10,000-lb high revolving-trolley manipulator

Table IV

DIMENSIONS OF HEAD-WRIGHTSON-BROSIUS MOBILE MANIPULATORS (Fig. 23)

M/C capacity, lb		2000	4000	8000
Unladen weight, tons		11	12½	22
	Dimensions	ft in.	ft in.	ft in.
Overall length	A	17 11	18 6	21 2½
Overall width	B	9 3	10 6	9 7
M/C height to top of collector	°C	13 8½	13 8½	...
Head radius	D	5 6	5 9	7 6
Tail radius	E	12 9	13 0	15 0
Head reach from front of M/C frame	F	1 5	2 10½	4 9
Minimum parallel hoist height	G	2 1½	2 1½	2 4½
Parallel hoist range	H	2 3½	2 3½	2 6
Maximum hoist range, from floor	I = G + H	4 5	4 5	4 10½
Total lateral shift	‡—	0 12	1 6	2 0
Maximum overall width of grip levers	J	† 4 3	3 9	5 11½
Maximum jaw opening	K	† 2 6	1 10	2 9½
Minimum square billet	L	† 0 6	0 4	0 3½
Maximum square billet	M	† 2 0	1 10	2 0
Minimum round billet	N	† 0 5	0 4	0 3½
Maximum round billet	O	† 1 4	1 4	2 0

Manipulator capacity is given by the maximum allowable weight of a uniform square-section billet gripped across the corners. In all cases the c.g. of the billet is 10 ft from front-wheel centre

° M/C height is about 8 ft for diesel-powered manipulators

† Dimensions are for special grips. Standard jaw dimensions are as for 4000-lb machines

‡ Maximum lateral shift of 2 ft can be supplied, giving a corresponding increase in overall M/C width 'B'

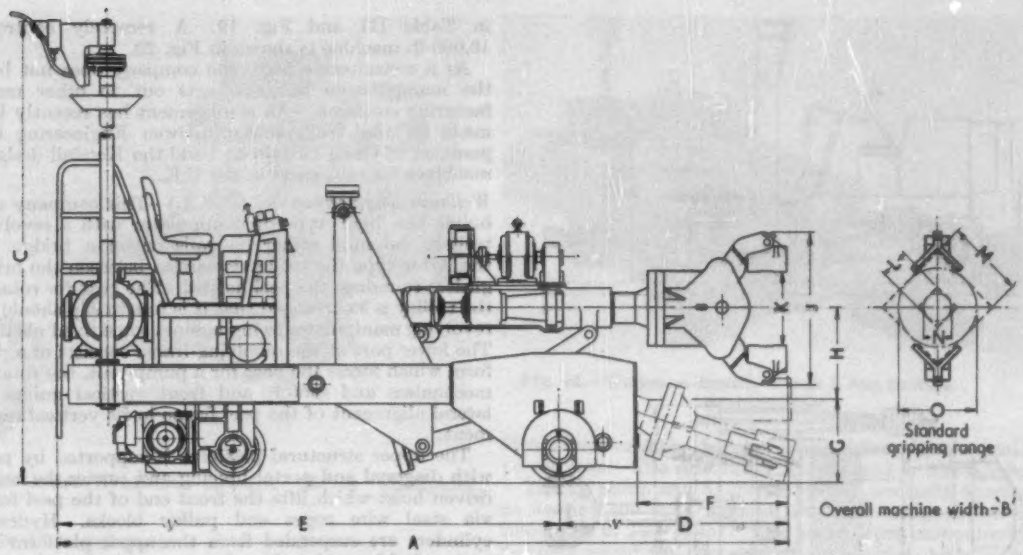


Fig. 23—Head-Wrightson–Brosius mobile manipulator

mounted lower on the trolley chassis and run between the girder flanges on a pair of rails attached inside the lower flange. Thus any tendency for the trolley to overturn about the front wheels may be checked by the rear wheels bearing against a rubbing plate welded to the inside of the top flanges of the main girders. (This alternative rail mounting is shown in Fig. 19.) The trolley travel speed is usually about 100 ft/min.

The trolley design incorporates some new features for effecting the required peel motions. The usual peel frame has been dispensed with, and instead the peel is suspended at the front in a continuous heavy link chain which passes round a sprocket attached to the peel with a universal connection. The peel sprocket is surrounded by a guide which operates between fixed slides on the main chassis. The chain passes over two head pulleys in the top of the trolley to a horizontally disposed peel-rotating sprocket in a sliding housing. The sprocket is driven by either an electric or hydraulic motor. The housing may be moved fore and aft in guides by two hydraulic cylinders, thus raising or lowering the front of the peel. Hydraulic accumulators connected in the line alleviate forging shocks. This system gives a level or inclined hoist speed of 6 in./s.

The rear end of the peel passes through a spring-loaded spherical seat and is supported by vertically opposed levelling cylinders and horizontally opposed skewing cylinders. This supporting mechanism embodies double-acting springs to alleviate shocks in the line of the peel. The sprocket attached to the peel can move in its guide fore and aft and swivel to maintain the line of tension in the chains, the peel assembly then being free to float and transmit forging shocks to the springs. The movement which may thus be accommodated is

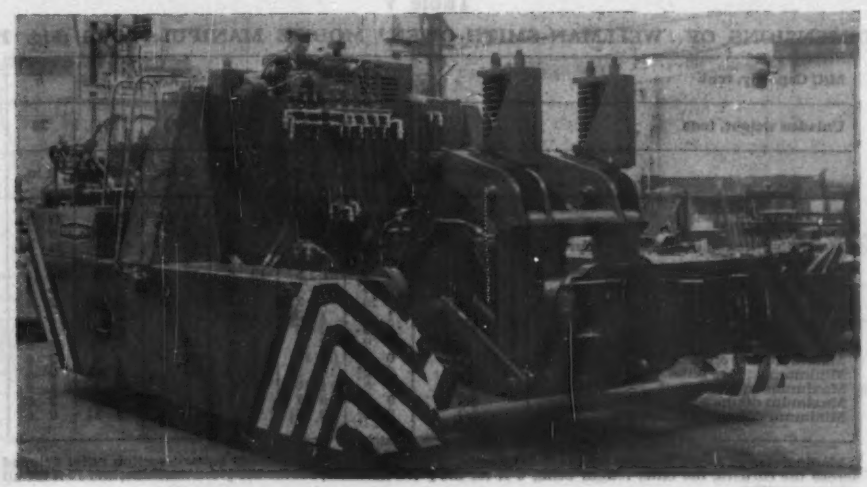


Fig. 24—Head-Wrightson–Brosius 8000-lb mobile manipulator

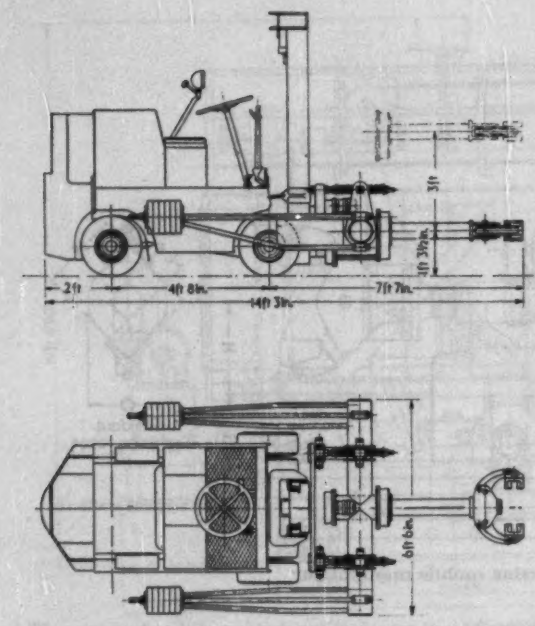


Fig. 25—Head-Wrightson–Brosius 500-lb Manipulet

referred to in Table III as 'traverse accelerator movement.' The hydraulic circuit operates at 1000 lb/in².

The grip head is operated by a single-acting hydraulic cylinder at the rear of the peel. The grips are closed by the application of pressure and opened by a spring system. The speed of rotation of the head is 20 rev/min.

The driver may be positioned offset to one side at the rear end of the machine, but manipulators can be supplied with remote control, enabling the operator to be positioned at a convenient point in the forge. The normal range of capacities is from 2000 lb to 12,000 lb but the company is prepared to offer designs for machines up to 150,000 lb. Details of the normal range are given in Table III and Fig. 19. A remotely controlled 10,000-lb machine is shown in Fig. 20.

As a consultative body the company does not build the manipulators but contracts out to other manufacturing concerns. An arrangement has recently been made for the Wellman-Smith-Owen Engineering Corporation of Great Britain to build the Kendall-designed machines for customers in the U.K.

Wellman Engineering Co. (U.S.A.)—This company only builds the 'high' type of manipulator with a revolving trolley, mounted either on rails or on a bridge. In the latter type the trolley is carried between the bridge girders to reduce the peel height. The gear for rotating the trolley is so arranged that it is free to slip should the revolving manipulator swing against some fixed obstacle. The lower part of the revolving frame consists of a platform which forms the base for a pump unit, the rotating mechanism and motor, and front vertical guides for lateral alignment of the peel frame in its vertical movement.

The upper structural platform is supported by posts with diagonal and portal bracing and carries the motor-driven hoist which lifts the front end of the peel frame via steel wire ropes and pulley blocks. Hydraulic cylinders are suspended from the upper platform and with suitable guides they form a vertically adjustable rear pivot link for the peel frame. This frame provides bearings in which the peel may be rotated on its axis by a geared electric motor. The rotational drive incorporates a controlled torque coupling to prevent damage to the mechanism if the motor should be energized when a forging is locked in the press or the peel checked during rotation.

The horizontal loads imparted to the peel during forging are absorbed by a spring-loaded trunnion-bearing at the rear of the frame. Vertical loads are taken by springs attached to the front-hoist cable sheaves and the rear cylinder brackets. The gripping mechanism is actuated by an oil cylinder situated at the rear of the peel frame. The electric power pickup is usually provided by cable to a set of collector rings on a pedestal above the top platform.

Standard manipulators are of 5000 and 10,000-lb capacity but machines up to 24,000 lb can be supplied. The 10,000-lb machine is shown in Figs. 21 and 22.

Table V

DIMENSIONS OF 'WELLMAN-SMITH-OWEN' MOBILE MANIPULATORS (Fig. 27)

M/C Capacity, tons		½	¾	1	2	3	5
Unladen weight, tons		3½	7½	10½	15½	19½	24
	Dimensions	ft in.	ft in.	ft in.	ft in.	ft in.	ft in.
Overall length	A	10 8½	14 3½	16 11	17 11½	19 11	22 1½
Overall width	B	4 9	6 7½	7 8	8 2	8 9½	9 9
M/C Height to top of collector (Approx.)	*C	10 6	10 9	10 9	10 9	11 0	11 0
Head radius	D	4 5½	6 5	7 1	7 7	8 1	8 4
Tail radius	E	6 2½	8 6	10 4	11 3	12 8	14 11
Head reach from front of M/C frame	F	3 4½	4 9½	5 5½	5 8½	5 11	6 0
Minimum parallel hoist height	G	1 10	2 2	2 2	2 3	2 3	2 4
Parallel hoist range	H	1 3	1 5	1 6	1 9	2 0	2 2
Maximum inclined hoist height	I	3 10	4 4	4 8	5 0	5 2	5 6
Maximum overall width of grip levers	†J	1 9	2 2	2 9	3 4	4 1	4 5
Maximum jaw opening	†K	0 9	0 11	1 2	1 6	2 0	2 0
Minimum square billet	†L	0 2½	0 3½	0 4	0 5	0 5½	0 6
Maximum square billett	†M	0 8	0 10	1 0	1 4	1 8	1 9
Maximum diameter billett	†N	0 9	0 11	1 2	1 6	1 11	2 0
Minimum diameter billett	†O	0 2½	0 3½	0 4	0 5	0 5½	0 6

Manipulator capacity is given by the maximum allowable weight of a uniform square-section billet gripped across the corners, the billet length being 6 ft for the ½-ton machine, 8 ft for the ¾-ton machine, and 10 ft for all other capacities

* M/C height is less for diesel-powered manipulators

† These dimensions depend on the type of grips fitted; standard values are given above

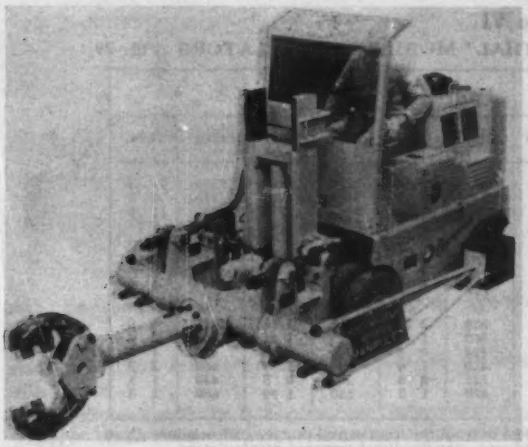


Fig. 26—Head-Wrightson–Brosius 500-lb Manipulet

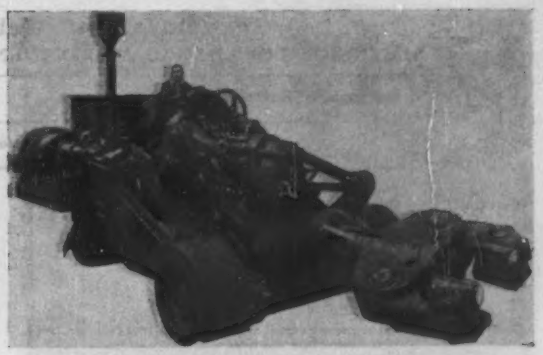


Fig. 28—Wellman-Smith-Owen 5-ton mobile manipulator

Mobile Manipulators

The Head-Wrightson Machine Co., Ltd. (*U.K.*)—The American Salem-Brosius designs are built by this company under licence. The machines supplied may have either an electric motor or an industrial diesel engine as the main power unit. In the electrically powered machine the current is supplied via collector gear on the mounted manipulator. The feed cable is connected to an automatic cable-reeling drum which may be fitted at a convenient point in the forge. A generator fitted to the diesel-powered model gives an auxiliary electric power supply.

On older models floor travel was effected by an electric motor hung on the rear-wheel frame and driving through reduction gearing. With this drive an electromagnetic brake, fixed to the motor, is automatically applied when the motor is stopped. The single central rear wheel is used for both traction and steering, the latter being carried out hydraulically by means of a double-acting cylinder. All the wheels have solid rubber tyres. All motions, including floor travel, are now hydraulically operated, deriving their power from a Hele-Shaw variable delivery pump driven by the main power unit. The maximum travel speed is 250 ft/min.

The oil pump and hydraulic system normally operate at about 1500 lb/in^2 though they are designed for a maximum of 2000 lb/in^2. The controls are conveniently grouped round the operator whose position, high up at the rear of the machine, affords a good view of the jaws. The control valve levers are fitted with locking plungers in the handles which prevent them being moved inadvertently. When a lever is in use, the plunger is depressed by the pressure of the operator's hand and the locking action is released.

The gripping action of the jaws is operated by a cylinder in the rear of the peel and the head may be continuously rotated in either direction by means of a hydraulic motor driving through an epicyclic gear. Provision is made for absorbing shock loads experienced when the rotating ingot is momentarily checked by the press or hammer. The peel rotation speed varies from 10 to 16 rev/min according to the size of the machine.

The parallel hoist motion is operated by a mechanism formed by bell cranks pivoted on the chassis. The upper arms of the cranks are connected to the peel frame. The lower arms of the levers are linked and the front pair operated by the level-hoist cylinder situated under the chassis. The pivot point of the back pair of cranks can be varied by the rocking-hoist cylinder which

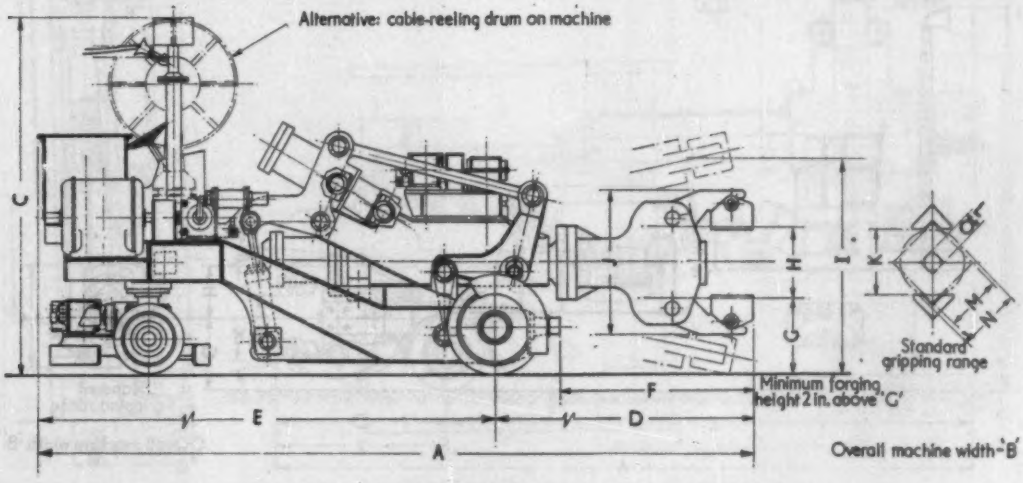


Fig. 27—Wellman-Smith-Owen mobile manipulator

Table VI

DIMENSIONS OF 'DANGO AND DIENENTHAL' MOBILE MANIPULATORS (Fig. 29)

M/C capacity, metric tons		1		2·5		5	
	Dimensions	mm	ft in.	mm	ft in.	mm	ft in.
Overall length	A	5185	17 0	6270	20 7	7390	24 3
Overall width	B	2510	8 3	3110	10 2	3120	10 3
M/C height to top of collector	C	3060	9 10	3500	11 6	3500	11 6
Head radius	D	1044	3 5	1820	5 11	1792	5 10
Tail radius	E	4155	13 7	4455	14 9	5605	18 4
Head reach from front-wheel centre	F	625	2 1	1250	4 5	1420	4 8
Minimum parallel hoist height	G	700	2 4	780	2 7	750	2 6
Parallel hoist range	H	375	1 3	480	1 7	460	1 6
Rocking hoist	α	12°	12°	14°	14°	11°	11°
	β	9°	9°	6°	6°	4°	4°
Maximum overall width of grip levers	I	860	2 11	1000	3 3	1415	4 8
Maximum jaw opening	J	500	1 8	575	1 11	710	2 4
Minimum square billet	K	120	0 5	200	0 8	430	1 5
Maximum square billet	L	410	1 4	530	1 9	660	2 2
Minimum round billet	M	120	0 5	200	0 8	430	1 5
Maximum round billet	N	470	1 7	550	1 10	680	2 3

Manipulator capacity is assessed with the billet centroid 3 m from the front-wheel centre. Dimensions given in the above table are for electrically driven machines and may vary for diesel-powered manipulators

enables the peel to be tilted to pick up work from the floor. The shocks transmitted during forging are absorbed by heavy coil springs at the front of the machine and the resulting movement is hydraulically compensated. A parallel hoist speed of about 2 in./s may be attained.

These machines may be constructed to incorporate lateral shift of the peel, enabling work to be forged in parallel-grooved swage tools without moving the whole manipulator. This feature is also valuable in reducing the necessity for accurate manœuvring of the manipulator, inasmuch as it is possible to move the work piece sideways over the anvil without moving the whole unit. The amount of shift varies according to the machine, but up to 12 in. of travel either side of normal may be provided.

Manipulators of 2000 and 4000-lb capacity, of the design shown in Fig. 23 have been built in the U.K., though the design range extends up 20,000 lb and some of the heavier machines have been built by the American company. New and improved designs have recently been announced and some details of the 8000-lb manipulator being built in the U.K. are included in Table IV. This machine is shown in Fig. 24. The overall dimensions of these new designs are generally smaller and the machines more streamlined in appearance.

The Head-Wrightson–Brosius 'Manipulet' attachment for heavy fork-lift trucks was also built by this company, but production has now been suspended. With this attachment the truck may be converted into a small mobile manipulator (Figs. 25 and 26). The main assembly is attached to the normal stacking unit of the fork-lift truck, though the vertical lift is restricted. The Manipulet has a rotating peel incorporating a detachable work head, several types of which are available for handling various forms of stock. Movements are hydraulically operated, power being supplied from the main hydraulic system of the fork-lift truck which, in addition to the normal controls for the standard machine, has two auxiliary hydraulic control valves fitted for the operation of the jaw gripping and rotating motions. The latter is effected by a hydraulic motor.

A shock-absorbing system is provided to counteract forging blows. Stabilizers are mounted on the front of the machine and are backed by heavy coil springs. Counterweights mounted on arms on either side of the truck and carried on a fulcrum on the truck stacker unit assist the stabilizers to absorb the shock loads and serve the additional purpose of moving the centre of gravity of the loaded vehicle towards the rear, aiding stability. The operator is protected from heat by a toughened

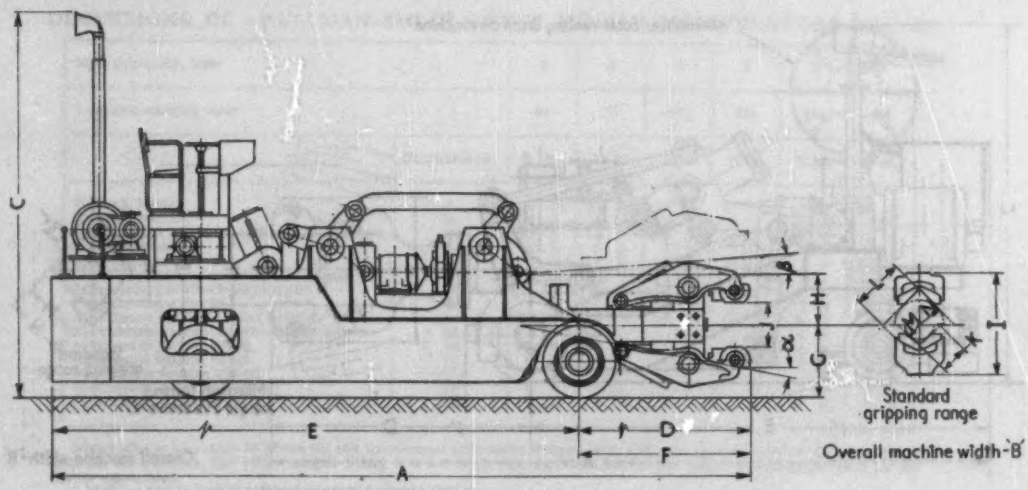


Fig. 29—Dango and Dienenthal mobile manipulator

Fig. 30—Dango and Dienenthal 2·5-ton mobile manipulator

glass shield and from counterweight vibration by steel side guards.

The Wellman-Smith-Owen Engineering Corporation Ltd. (*U.K.*)—These manipulators, which are of British design, may be supplied with either diesel or electric power units.

The prime mover for the electric machine is usually an a.c. electric motor of the totally enclosed squirrel-cage type, although a d.c. motor can be provided. Current is collected through a feed cable connected to a swivelling automatic cable-reeling drum which may be mounted on the machine or in the forge at some convenient position. Diesel-engine prime movers are of the heavy industrial type, radiator cooled with hand starting or self-contained electric starting.

All six motions incorporated in the manipulators are hydraulically powered by a pump unit which, by means of an automatic control, ensures a variable delivery to meet the demands of each motion. The working pressure in the system varies between 400 lb/in² and 1000 lb/in². All the motions, except steering and travel acceleration, are controlled by lever-operated valves conveniently arranged in front of the operator's position. The steering is operated by a wheel, and travel acceleration by a foot pedal.

The parallel hoist motion is operated by a linkage formed by bellcranks pivoted on the peel frame. The

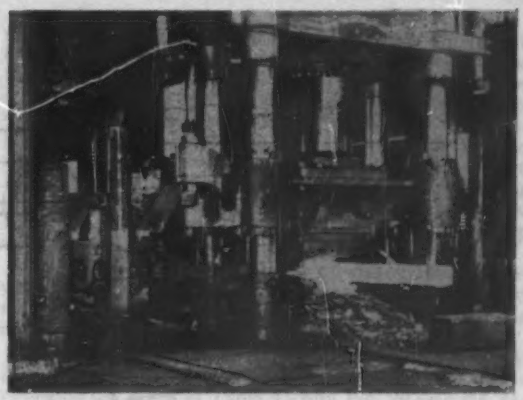


Fig. 32—Kendall tool manipulator working with 1500-ton press

vertical members of the bellcranks are connected by tie-rods and the horizontal members attached to the chassis, at the rear by the rocking hoist cylinders and at the front by support links which are members of a horizontal floating mechanism. Arranged between the rear bellcranks is a trunnion-mounted hoisting cylinder, the piston of which is pivotally fitted to the peel frame. The parallel-hoist speed is 6 in./s on the small machines but less for the larger-capacity manipulators.

In addition to the vertical resilience through the parallel hoist mechanism, horizontal floating is also provided by the front support links which are pivoted to the chassis and connected to recoil springs.

The rocking-hoist motion, which enables the grips to be lowered to the floor or raised above the highest parallel position, is operated by double-acting hydraulic cylinders which raise or lower the rear bellcranks, thereby rocking the spindle frame about the pivoted connection of the front bellcranks to vertical links of the recoil

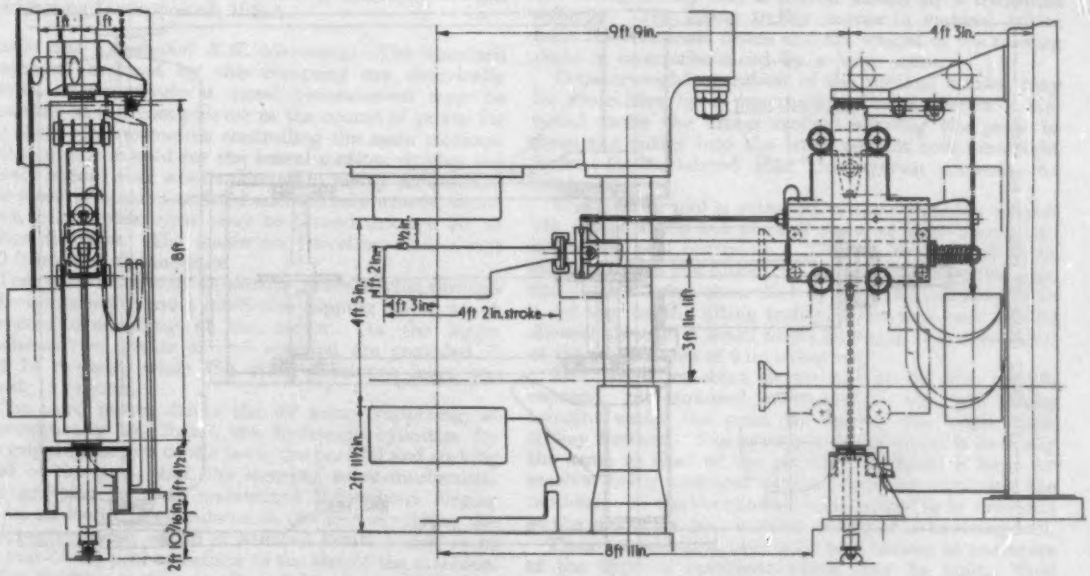


Fig. 31—Kendall tool manipulator for 1500-ton press

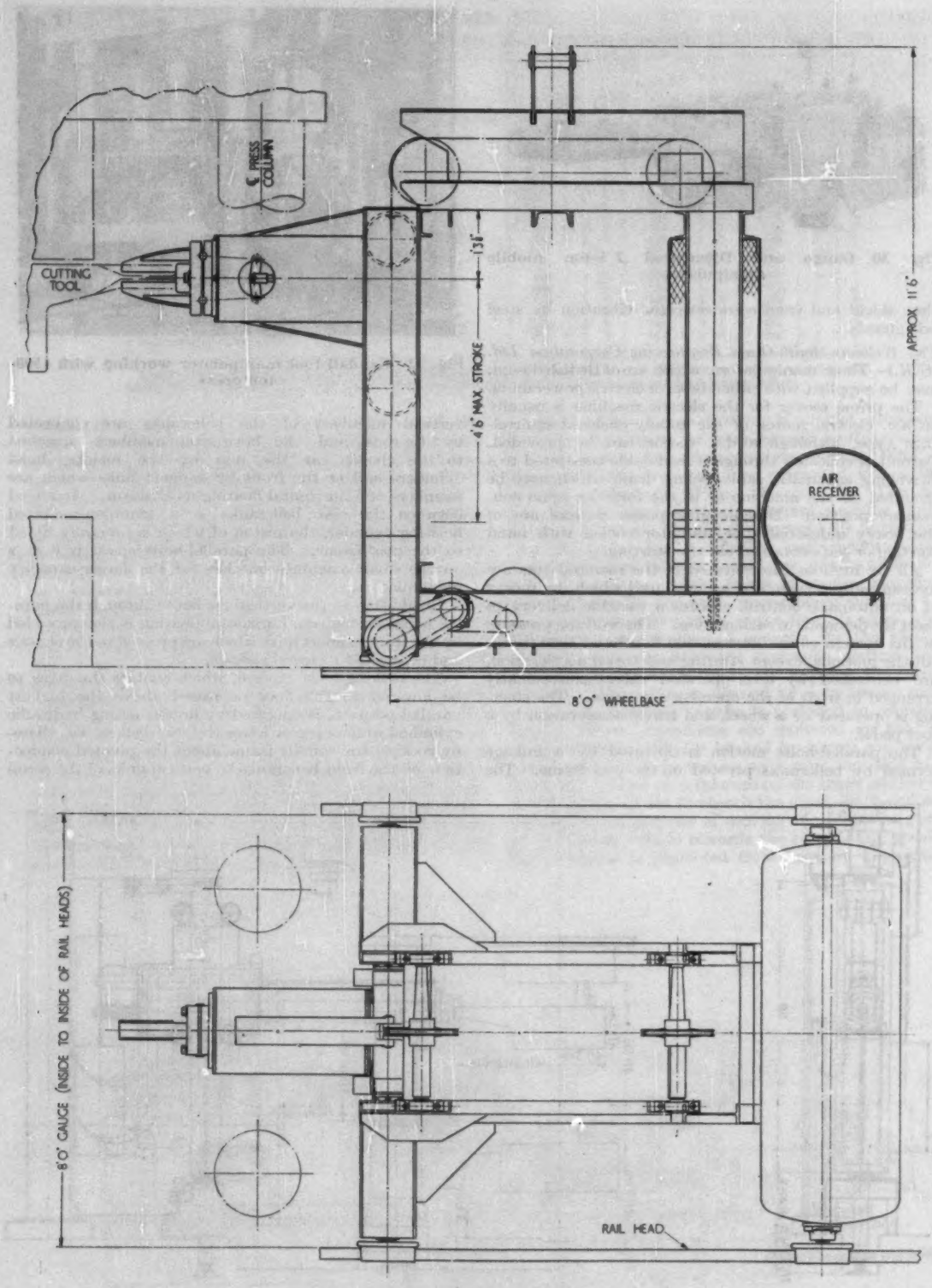


Fig. 33—Kendall 1000-lb rail-mounted tool manipulator

mechanism. If this motion is overloaded, oil is released from the cylinders by a hydraulic relief valve, thus preventing the machine being loaded beyond its designed capacity.

Rotation of the grip head is effected by a hydraulic motor capable of running continuously in either direction, and driving through several stages of totally enclosed gearing. The grip head can be stopped accurately in any desired angular position, and any shock transmitted in a rotary manner while forging is absorbed by a slip coupling fitted to the gears close to the main spindle but adjusted to transmit the full peel turning torque before slip occurs. The maximum rotational speed provided varies from 20 rev/min on the ¼-ton manipulator down to 10 rev/min on the 5-ton machine.

The grips are operated by levers engaging in the crosshead arranged in the grip head and actuated by a pull-rod connected to a double-acting hydraulic cylinder mounted at the rear of the spindle frame. To permit rotation of the grips while taking the thrust of the grip motion, spherical roller bearings are provided in the piston. The gripping action is maintained against possible oil leakage by a piston–spring hydraulic accumulator.

The manipulators are mounted on solid-tyred wheels, those at the front being equipped with hydraulically operated brakes.

Twin hydraulic motors drive the rear wheels, giving a maximum speed of 250 ft/min on all machines. The motors are piped in parallel and as each motor drives a single wheel a simple differential action is obtained without the need of complicated gearing. The castor unit is pivotally mounted on a steering centrepost which provides 180° movement through a double-acting hydraulic cylinder operating a toothed ram engaging a pinion mounted on the centrepost. The 90° angular movement in each direction permits the manipulators to turn completely about the centre of the front axle.

Details of the standard range of six capacities, from ¼ to 5 tons, are given in Table V and Fig. 27 and a 5-ton machine is shown in Fig. 28.

Under a recent agreement this company will also produce rail-mounted machines to the designs of Kendall Contracting Incorporated, U.S.A.

Dango and Dienenthal K.G. (Germany)—The standard machines produced by this company are electrically driven. Alternatively a diesel generator-set may be mounted on the manipulator as the source of power for the three electric motors controlling the main motions.

One motor is used for the travel motion, driving the closely spaced rear wheels through a heavy differential. The steering is servo-assisted and the rear wheels, which have solid rubber tyres, may be turned through 90° in either direction. The maximum travel speed is about 200 ft/min for all machines.

The peel is rotated by an electric motor driving through reduction gearing and a multi-disc slipping clutch which prevents overloading of the motor. On the larger machines two speeds of peel rotation are provided, 7 and 14 rev/min, while the small machines have one speed, 18 rev/min.

The third motor drives the oil pump supplying, at approximately 850 lb/in², the hydraulic cylinders for the gripping motion of the jaws, the parallel and rocking hoist of the peel, and the steering servo-mechanism. The gripping force is maintained throughout forging by an air-loaded accumulator in the line supplying the gripping cylinder, which is situated either inside or at the rear of the peel according to the size of the machine.

The hoisting motion is effected by the usual system of linked bellcrank levers actuated by a hydraulic cylinder. The auxiliary frame containing the peel is suspended from the bellcrank levers which pivot at the main frame. The suspension at the front of the peel frame is by spring loaded links and at the back by cylinders which are used to effect the tilting motion of the peel. Forging shocks are absorbed by the springs and rubber cushions as well as the hydro-pneumatic accumulators which are inserted in the lines to the hoisting motion cylinders. The maximum parallel hoisting speed varies from about 3 in./s on the largest manipulator up to 5½ in./s on the small machines.

All cylinders are controlled by hand-operated four-way valves grouped round the operator. His position may be arranged either offset at the front of the machine or in the centre at the back.

Manipulators of five capacities are manufactured: ¼, ½, 1, 2½, and 5 metric tons. Details of the three larger machines are given in Table VI and Fig. 29 and the 2½-ton machine is shown in Fig. 30.

Salem-Brosius Incorporated (U.S.A.)—Manipulators are designed for eight capacities ranging from 2000 to 20,000 lb. Since 1955 some of these designs have been built in the U.K. under licence by the Head-Wrightson Machine Company.

Tool Manipulators

The Wellman-Smith-Owen Engineering Corporation Ltd. (U.K.)—Under a recent agreement, this company now undertakes the manufacture of tool manipulators to the designs of Kendall Contracting Incorporated of the U.S.A. These machines are specially designed to hold the cutting tools under the press crosshead, thus eliminating the laborious methods used when manhandling the heavy tools.

The manipulators may be rail mounted or have the main frame fixed at the side of the press. Figures 31 and 32 show one of the latter types, designed for use with a 1500-ton press.

The tool is moved under the press from one side and since the main frame is fixed, the tool-holder slides in the lifting trolley and is moved axially by a hydraulic cylinder. The lifting trolley moves in vertical guides built into the main frame and the weight of the moving parts is counterbalanced by a large mass.

Counterweight operation of the vertical motion may be overridden by a pneumatic cylinder vertically disposed under the lifting trolley, allowing the press to force the cutter into the work against counter-weight force. It is claimed that this system protects the mechanism.

The cutting tool is attached to the cutter bar or peel via plates which are pivoted together both above and below the peel centreline. This allows the tool to be deflected from the horizontal without bending the peel, the motion being controlled by a linkage connected to a cylinder on the lifting trolley. The peel may also be skewed through a small angle, giving a tool movement at the press centre of 6 in. either way.

The larger machine shown in Fig. 33 is a 1000-lb capacity rail-mounted manipulator, the tool being brought under the press by driving the whole main trolley forward. The principle of operation is basically the same as that of the previous machine, a large air receiver being mounted on the frame for supplying the motions. A double-pivoted tool mounting is provided at the end of the peel to allow tilting of the cutting tool.

These two designs have only been chosen as examples of the type of machines which may be built. Tool manipulators are not standard and have to be designed to suit particular requirements.

Vacuum-melting of Steels

By H. C. Child, B.Sc., A.I.M., and G. T. Harris, M.A., F.Inst.P., F.I.M.

SYNOPSIS

The equipment used for vacuum induction and consumable-electrode vacuum-arc melting is described and an account given of how each process is carried out and the attendant advantages. The main applications are discussed and examples given of the improvement in properties achieved. 1641

ALTHOUGH THE CONCEPTION of vacuum-melting goes back to the last century, it is only during the last 10 years that there has been a significant production of vacuum-melted metal. The early vacuum-melting furnaces enclosed a typical high-frequency induction furnace in a vacuum-tight chamber and were able to melt and cast completely *in vacuo*. Until recent times, however, the vacuum used was of the order of a few mm of mercury and the process could be regarded as one of protective-atmosphere melting rather than a true vacuum-purification process.

Early furnaces of this type were installed at Heraeus Vacuum-Schmelze in Germany and at Telegraph Construction and Maintenance Company in the U.K. It was appreciated at this time that by using such relatively high pressures as 1–10 mm Hg excessive oxidation could be avoided during melting and that alloys could be produced having a somewhat lower gas content than air-melted material. Also the avoidance of oxidation of the alloying constituents enabled much closer specification to be met.

High-vacuum metallurgy developed rapidly after the war when the superior equipment which had been developed for other applications and furnaces became available for operating at pressures of 10^{-3} mm Hg and better. Such furnaces enabled significant vacuum purification to occur during melting and opened up a new field of metallurgy.

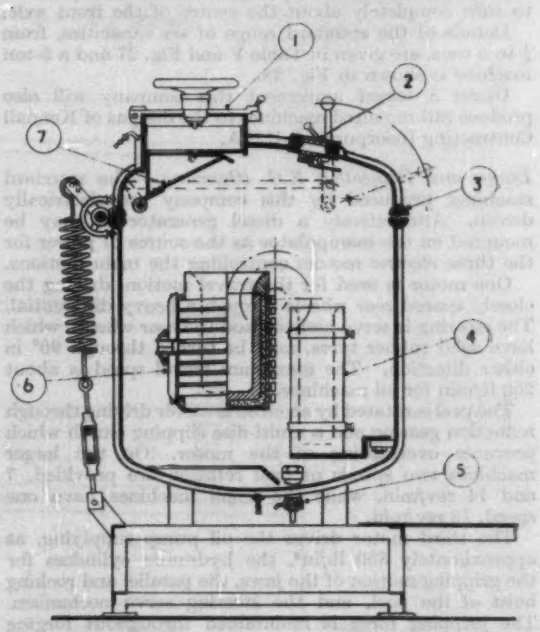
Simultaneously with this development of vacuum-induction furnaces, it became apparent that the refractory metals such as molybdenum and titanium could not be melted satisfactorily owing to the limitations of crucible materials. Non-consumable tungsten-electrode arc furnaces using a water-cooled copper crucible were developed for this type of material and these furnaces used an argon atmosphere owing to the difficulty of stabilizing an arc with a non-consumable electrode *in vacuo*. Later developments led to the use of consumable-electrode arc furnaces operating in a high vacuum. Owing to the success of these furnaces melting refractory metals, attention was drawn to their possibility for steel.

This paper will deal with high-vacuum induction and consumable-electrode arc melting of steels and will describe modern equipment for both processes. The capabilities and limitations of these complementary processes will be discussed and examples given of the properties which can be achieved.

Vacuum-Induction Equipment

Enclosing an h.f. induction furnace in a vacuum chamber gives rise to several technical problems. Perhaps the greatest of these is the problem of avoiding electrical discharges under vacuum conditions. For this reason there was a tendency for the earlier furnaces to use a coil voltage of not more than 230 V, and for the normal design of multi-turn coil this meant using a generator of 2–5 kc.

An example of one of the earliest commercial units is given in Fig. 1. Units of this kind have been produced for melting either 20 or 60 lb of steel. The containing vessel is of a double-walled water-cooled construction, made in stainless steel, and the entire coil and crucible assembly pivots on a rotating coaxial seal which carries both the water and power supplies for the coil. Above the crucible is the charging device, whereby additional base charge and alloying additions may be added to the melt without breaking the vacuum. There is also a viewing port with a protection shield. Casting is normally done directly



1. Alloy addition hopper
2. Observation window
3. Vacuum seal for furnace lid
4. Ingot mould
5. Electrical and water connection
6. Furnace
7. Alloy addition chute

Fig. 1—Diagrammatic view of Geraetebau-Anstalt-Balzer 20-lb vacuum-induction furnace (VSG 10)

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Mr. Harris is Research Director and Mr. Child is Research Manager at William Jessop and Sons, Ltd., Sheffield.

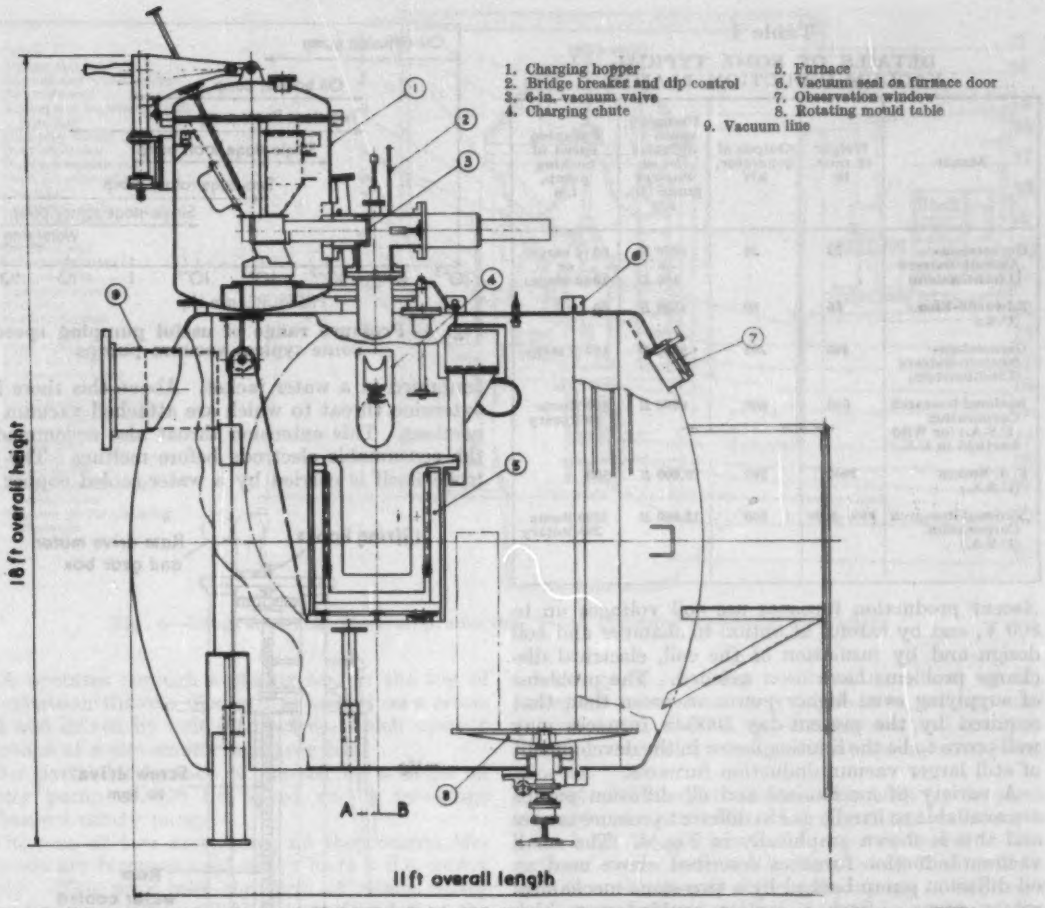

Fig. 2—Diagrammatic view of Wild-Barfield 600-lb vacuum-induction furnace installed at William Jessop and Sons, Ltd.

from the crucible into the ingot mould situated at the front of the vacuum chamber.

While simple furnaces of this type are ideally suited to laboratory operation, for production purposes somewhat more complicated arrangements are required. In particular it becomes necessary to be able to re-charge the furnace without breaking the vacuum so that semi-continuous operation of the furnace can be achieved. An example of such a unit for melting 600 lb of steel which is installed at the authors' works is shown in diagrammatic form in Fig. 2 and pictorially in Fig. 3. There is a vacuum valve between the alloy charging device and the furnace chamber, and this, in conjunction with a rotating mould table holding sufficient moulds for several heats, allows the unit to be run semi-continuously There is provision for sampling the melt, for breaking bridges during melt-down, and for taking dip-thermocouple readings, all without breaking the vacuum.

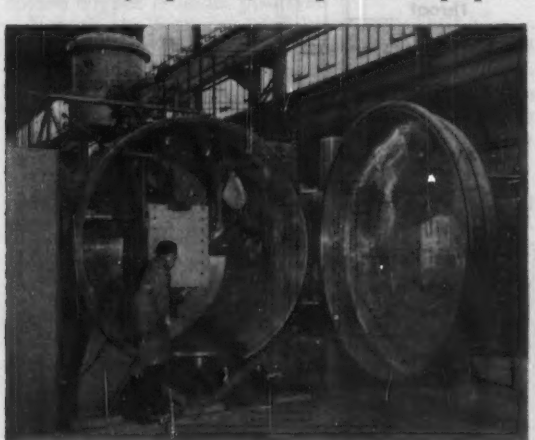

Fig. 3—Pictorial view of 600-lb vacuum-induction furnace

If more continuous operation is required, it becomes necessary to be able to introduce moulds to the unit through a vacuum lock in a similar way to the alloy charges. Such an item is only justified economically on larger units and 3000-lb furnaces of this type[1] have been produced.

With larger production furnaces the earlier policy of restricting the coil voltage has had to be abandoned owing to the difficulty of designing electrical systems to operate at the high amperages which were needed.

Table I

DETAILS OF SOME TYPICAL VACUUM-INDUCTION PLANTS

Maker	Weight of melt, lb	Output of generator, kW	Pumping speed of diffusion (D) or booster pump (B), L/s	Pumping speed of backing pump, L/s
Gerastebau-Anstalt-Balzers (Liechtenstein)	22	30	1000 *D* or 500 *D*	50 (2 stage) or 10 (2 stage)
Edwards-Efco (U.K.)	86	50	1300 *B*	50
Gerastebau-Anstalt-Balzers (Liechtenstein)	440	200	8000 *D*	100 (2 stage)
National Research Corporation (U.S.A.) (or Wild Barfield in U.K.)	600	200	6000 *B*	500 Roots 50 Rotary
F. J. Stokes (U.S.A.)	2000	500	15,000 *B*	500
National Research Corporation (U.S.A.)	2400–3000	500	12,000 *B*	2300 Roots 200 Rotary

Recent production furnaces use coil voltages up to 800 V, and by careful attention to chamber and coil design and by insulation of the coil, electrical discharge problems have been avoided. The problems of supplying even higher power *in vacuo* than that required by the present-day 3000-lb furnaces may well prove to be the limiting factor in the development of still larger vacuum-induction furnaces.

A variety of mechanical and oil diffusion pumps are available to handle gas in different pressure ranges and this is shown graphically in Fig. 4. The small vacuum-induction furnaces described above used an oil diffusion pump backed by a two-stage mechanical rotary pump. Such a system enabled very high vacuums to be achieved, i.e. 10^{-4} mm Hg. However, the pumping speeds were not very high in the pressure range 10^{-1}–10^{-3} mm Hg and practical experience in melting steels soon indicated that the bulk of the outgassing of steels occurred in this range.

Oil booster pumps having very high pumping speeds in this critical range have been developed recently,[2] and the well known Roots pump has been converted to vacuum applications.[3] It has not only the facility of handling large volumes of gases in this pressure range but has the added advantage of being a dry pump and of being able to deal satisfactorily with condensable vapours and fine solids. Because of this, modern production furnaces use these pumps either singly or in combination. For example, the 600-lb vacuum-induction furnace described earlier, uses two oil booster pumps backed by a Roots pump which in turn is backed by a conventional single-stage mechanical rotary pump.

A comparison of the vacuum and electrical equipment found suitable for several sizes of furnaces is given in Table I.

Vacuum-arc Furnaces

A schematic diagram of a small consumable-electrode arc furnace used in the authors' laboratory is shown in Fig. 5. This consists of a copper crucible

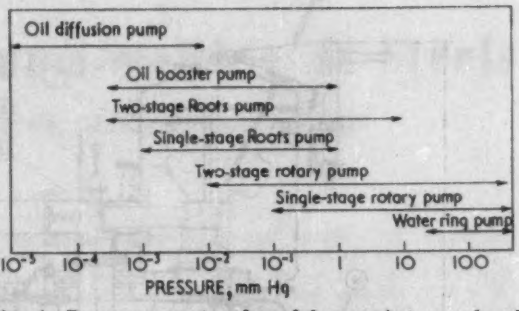

Fig. 4—Pressure range of useful pumping speeds of some typical vacuum pumps

contained in a water jacket. Above this there is an extension throat to which are attached vacuum connections. This extension throat also accommodates the consumable electrode before melting. The electrode itself is carried by a water-cooled copper ram

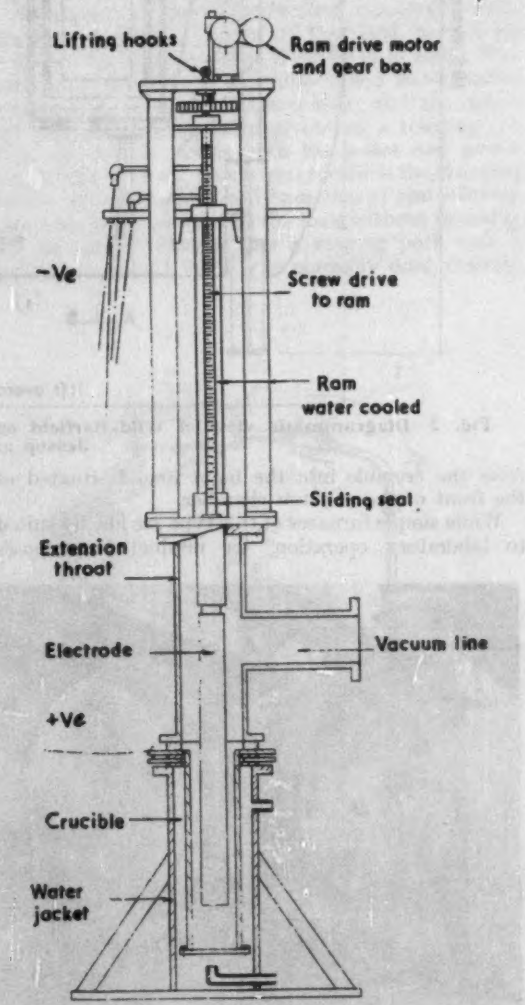

Fig. 5—Diagrammatic view of research department consumable-electrode furnace

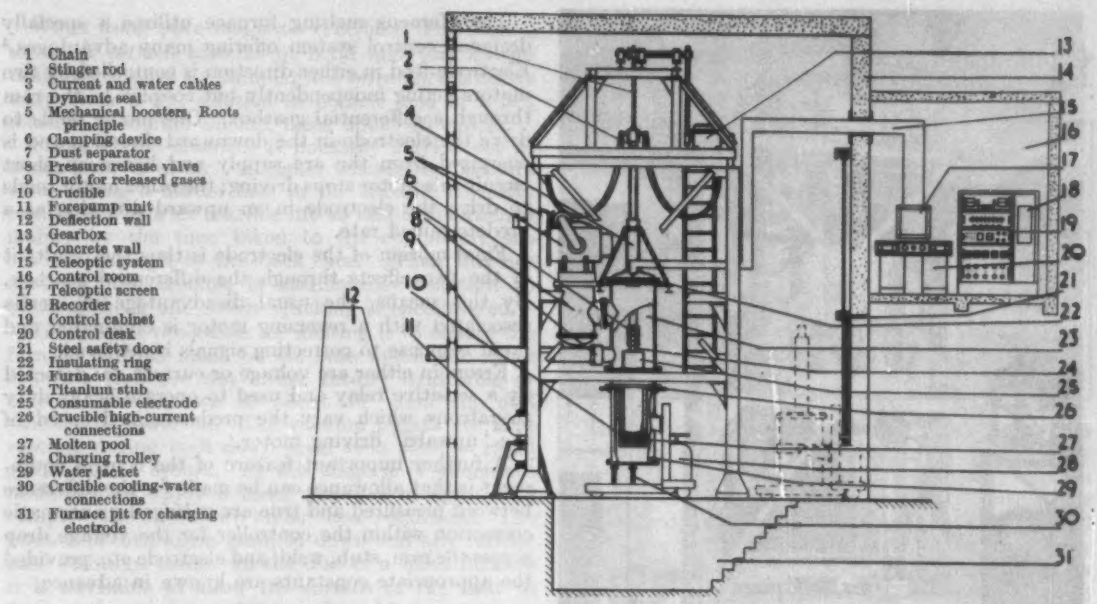

Fig. 6—Diagrammatic view of production 3-ton consumable-electrode furnace

which operates through a sliding seal in the top of the extension throat. The ram is carried on a cross-head and driven by twin lead-screws, which operate by means of a servomotor and gear box.

This particular furnace is pumped by a single oil booster pump of 850 l./s speed and a two-stage mechanical rotary pump.

With one or two exceptions, all the consumable-electrode arc furnaces used today have a d.c. power supply. This may take the form of either rotary generators or rectifiers. It has been found that the problems of arc stability and arc control are much simpler using a d.c. power supply although a.c. furnaces have been operated successfully particularly with molybdenum furnaces employing a high current density. The ram is normally negative and the water-cooled copper crucible positive.

Not all the furnaces used have been built to the same principle. Some of the earlier furnaces enclosed the whole of the electrode and the transport mechanism inside the vacuum. This generally took the form of an electrode carrier which was lowered by an endless chain-drive. This kind of furnace had the advantage of requiring less head room but all the transport mechanism was inside the vacuum and subject to the various metallic deposits and condensable vapours which were prevalent during the melting process.

Table II

DETAILS OF CONSUMABLE-ELECTRODE VACUUM ARC FURNACES AT WM. JESSOP AND SONS, LTD.

Ingot dia., in.	Ingot weight, lb	Electrode dia., in.	Pumping speed of booster pump, l./s	Electrical power available, A
6	70	3	850	3000
9	500	6	1300	10,000
12	1000	9	1300	10,000
20	6720	16	4500	20,000
24	6720	20	4500	20,000

Most of the modern furnaces are built on the same principle as that illustrated in Fig. 5 and an example of a large 3-ton Heraeus[4] furnace installed at the authors' works is shown in Figs. 6 and 7. It will be seen that this closely follows the design of the small furnace but that in this instance the whole of the furnace body is a permanent fixture and the electrode is charged from underneath by a moving crucible trolley. In the case of the laboratory furnace the water jacket was a fixture and the whole of the top part of the furnace was removed by crane. Earlier production furnaces used in the authors' plant adopted the same principle.

To indicate the capacities of the various equipments used, some data for the Jessop production furnaces is given in Table II. It may be noted that the largest furnaces in the U.S.A. can now melt 30-in. dia. ingots weighing up to 6 or 8 tons.

The units for steel melting invariably use oil booster or Roots pumps. The latter are more expensive for a given capacity but due to their ability to handle steam they are a safeguard as they prevent steam-pressure build-up in the furnace if the copper crucible is penetrated by the arc. Therefore it is advisable to use a Roots pump in parallel with an oil booster for maximum economy and safety. Earlier furnaces used conventional rotary pumps for backing, but the latest installation at the authors' works uses Roots pumps and a water ring pump in series for this purpose (*see* Fig. 4).

The furnaces are normally operated remotely for safety reasons although it is accepted that steel-

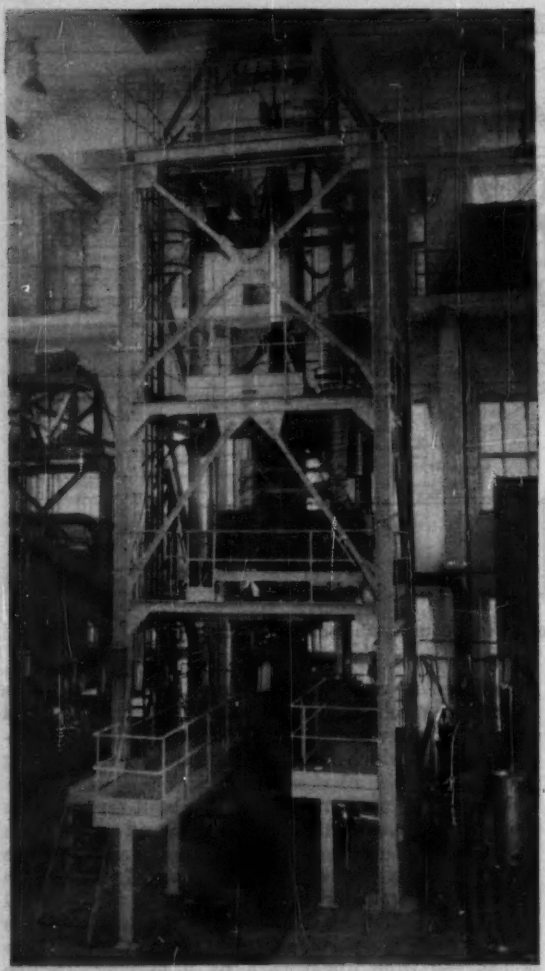

Fig. 7—General view of 3-ton Heraeus consumable-electrode furnace installed at William Jessop and Sons, Ltd.

melting is much less hazardous than melting titanium and zirconium. The electrode is fed automatically using the arc-voltage for control.

The small experimental furnace uses a simple d.c. servo-amplifier and motor to maintain the required arc voltage. 'Arc' voltage (measured between ram-head and crucible) is compared with a preset reference voltage and any error amplified electronically and used to energize a split-field servomotor. Through suitable reduction gearing the servomotor drives the electrode either up or down to correct the error. Some velocity feed-back is included in the control-loop to stabilize the system against hunting.

The control system for the earlier production furnaces is similar in principle, being based on error in arc voltage as measured between the crucible and the current-carrying shoes bearing on the electrode. Owing to the increased power requirements, however, amplification of the error signal is by a Metadyne rotating cross-field amplifier which provides reversible d.c. to the drive motor.

The Heraeus melting furnace utilizes a specially designed control system offering many advantages.[4] Electrode-feed in either direction is controlled by two motors acting independently but coupled to the ram through a differential gearbox. One motor tends to drive the electrode in the downward direction and is energized from the arc supply and hence on short circuit this motor stops driving; the other motor tends to drive the electrode in an upward direction at a predetermined rate.

Final motion of the electrode is thus the resultant of the two effects through the differential gearbox. By this means, the usual disadvantage of inertia associated with a reversing motor is eliminated and rapid response to correcting signals is achieved.

Errors in either arc voltage or current are detected by a sensitive relay and used to operate heavy-duty thyratrons which vary the predetermined speed of the 'upward' driving motor.

A further important feature of the control equipment is that allowance can be made for the difference between measured and true arc voltage by automatic correction within the controller for the voltage drop across the ram, stub, weld, and electrode etc. provided the appropriate constants are known in advance.

The Vacuum-Induction Process

A wide variety of crucible materials including pure magnesia, commercial magnesia, alumina, 70% magnesia–30% alumina, 90% alumina–10% silica, zirconia, and beryllia have been used for vacuum-induction melting. For steel melting, the bulk of production has been carried out using magnesia or the magnesia–alumina mixture.

Although pre-fired crucibles have been used for small laboratory furnaces, larger production furnaces invariably frit the crucible *in situ* using either a graphite or steel former. Some producers prefer the use of a metal former as it enables them to make a heat simultaneously with the firing operation. The use of a graphite former, however, permits higher fritting temperatures and gives the opportunity for examination of the crucible and fettling before melting is begun.

The grading of the powders used is important and the following has been found suitable:

4 parts	10 — 20 mesh
3 ,,	20 — 80 ,,
2 ,,	80 — 150 ,,

Table III

EFFECT OF TIME UNDER VACUUM (10^{-3} mm Hg) ON GAS CONTENT OF SOME TYPICAL ALLOYS

Alloy	Temp., °C	Gas, p.p.m.	Time at Pressure 10^{-3} mm Hg			
			1 min	10 min	30 min	60 min
A	1480	O_2	40	60	15	20
		N_2	50	60	40	35
B	1410	O_2	20	15	10	5
		N_2	40	20	10	3
C	1450	O_2	25	20	10	20
		N_2	25	30	50	5
D	1470	O_2	10	5	5	5
		N_2	40	30	40	40

When using pure magnesia crucibles, it is normal to use a certain amount of bond and this is conveniently applied by damping the refractory powders with either a 3% solution of boracic acid or a 5% solution of sodium silicate, using about 75 cm³/lb.

Firing of the crucibles is normally carried out at about 2000° C in air. A higher fritting temperature while giving a harder face to the crucible normally results in a shorter crucible life as this is determined mainly by the time taken to frit completely the crucible through to the back face. When this has occurred, the crucible is insufficiently resistant to thermal shock and severe cracking is encountered.

The normal procedure for melting is to charge the furnace with as much of the base metal and other elements that are not either readily oxidizable or volatile, pump down to about 10^{-3} mm Hg, and switch the power on. The vacuum pumps are kept running during melt down until such time as rapid gas evolution occurs. At this stage it is sometimes preferable to apply a small pressure of argon and complete the melt down under these conditions. The furnace is then again pumped down and any further base additions made. In the case of a small furnace it is advisable to allow the surface of the melt to freeze before making additions, but this is not necessary on larger furnaces.

When the base charge has been degassed to a vacuum of about 10^{-3} mm Hg, readily oxidizable and volatile additions are made. In most cases, the melt is again pumped down to 10^{-3} mm Hg but if the addition is of an exceedingly volatile nature, it is more prudent to make the addition under argon and to cast immediately. Casting is normally carried out using a few cm Hg pressure of argon as this results in less metal/mould reaction.

The degasification of the melt is a function of pressure, time, and temperature, and the effect of these on the O_2 and N_2 content of four typical alloys has been studied. Compositions are as follows:

Element, %	*Alloy*			
	A	*B*	*C*	*D*
C	0·15	0·2	1·0	0·75
Mn	0·6	...	0·5	0·35
Si	0·3	...	0·25	0·4
Ni	...	base	...	...
Cr	11·8	10·0	1·5	4·2
Mo	0·45	5·0	...	0·5
W	...	...	...	18·5
V	0·3	...	...	1·3
Nb	0·25	...	...	...
Co	...	20·0	...	...
Ti	...	1·5	...	...
Al	...	4·5	...	...

Table IV

EFFECT OF PRESSURE ON GAS CONTENT OF SOME TYPICAL ALLOYS

Alloy	Temp., °C	Gas, p.p.m.	Pressure in mm Hg					
			760	100	10	1	0·1	0·001
A	1420	O_2	70	60	55	30	20	20
		N_2	90	100	85	80	20	40
B	1410	O_2	30	15	30	15	35	25
		N_2	20	50	15	10	30	15
C	1470	O_2	25	25	30	10	15	...
		N_2	50	70	45	25	40	25

Table V

EFFECT OF TEMPERATURE AT PRESSURE OF 10^{-3} mm Hg ON GAS CONTENT OF SOME TYPICAL ALLOYS

Alloy	Gas, p.p.m.	Temperature, ° C								
		1400	1425	1450	1475	1500	1525	1550	1575	1600
A	O_2				35	30		50		50
	N_2				80	55		60		40
B	O_2	30	25	20	20	25				
	N_2	10	20	15	20	5				
C	O_2		20				55	5		
	N_2		35		35		20	30		
D	O_2		10	10	10	10				
	N_2		50	40	40	30				

The experiments were all carried out on 20-lb heats melted in a magnesia crucible using virgin alloy charges. The gas contents were determined by vacuum fusion of samples taken progressively during the various experiments. The four alloys were held molten at a temperature suitably related to the melting points and the effect of holding for times up to 1 h at 10^{-3} mm Hg was studied. The results are given in Table III. Both the O_2 and N_2 contents tend to decrease progressively but the practical effect of holding under vacuum is mainly to reduce the N_2 content.

The effect of pressure is shown in Table IV. The heats were melted under 760 mm Hg of argon after evacuating the furnace chamber. After holding for 2 min at each pressure, a sample was taken. Again there is a progressive decrease in gas content with low pressure, but it is noteworthy that substantial degasification has occurred at 0·1 mm Hg.

Similarly, the effect of temperature may be seen from Table V. The bath was held for 2 min at each temperature and while the general trend is that higher temperatures result in lower gas content, in some instances, e.g. alloy *C*, there is an increase of oxygen at 1525° C due to a metal/crucible reaction. This also occurred with alloy *A* at 1550° C and 1600° C.

It may be concluded that, in general, super-heating the bath is not a very satisfactory way of aiding degasification, as it is also detrimental to the life of the crucible. A few minutes at 10^{-3} mm Hg with 50–100° C superheat is the best degassing technique for this furnace.

Although most operators have judged the progress of degasification of the metal by observing the vacuum pressure in the chamber, it has been pointed out by Jones[5] that the prevailing vacuum pressure is largely a function of the efficiency of the vacuum pumps used and that a more accurate guide to the state of the metal is the rate of pressure rise found in the chamber with the pumping system isolated.

For example, on the 20-lb laboratory unit, the authors found a pressure rise of 300μ in a 15-min period with no molten metal in the crucible (*see* Fig. 8). A nickel-base alloy was now melted in the crucible and when the base charge had been pumped to a vacuum of 10^{-3} mm Hg for 1 min, the pressure rise was again measured and this was repeated when the base charge had been evacuated for 1 min at

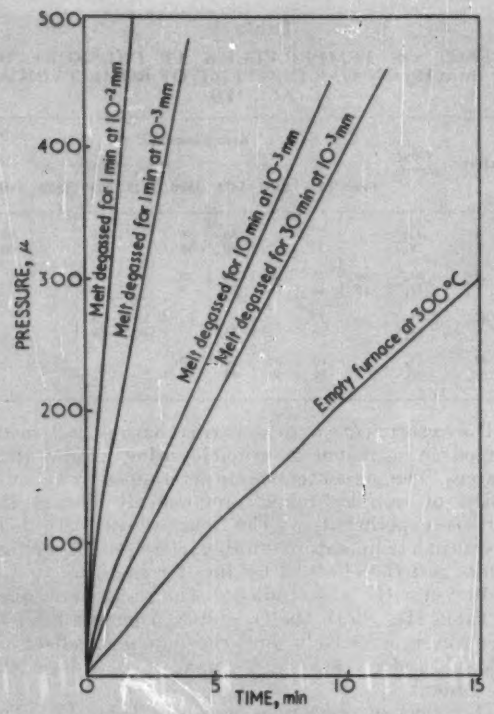
PRESSURE, μ
TIME, min
Melt degassed for 1 min at 10⁻³ mm
Melt degassed for 1 min at 10⁻³ mm
Melt degassed for 10 min at 10⁻³ mm
Melt degassed for 30 min at 10⁻³ mm
Empty furnace at 300°C

Fig. 8—Pressure rise tests on 20-lb vacuum-induction furnace after various outgassing procedures for the melt

10^{-3} mm Hg and 10 and 30 min at the same pressure. It will be seen from Fig. 9 that the rate of pressure rise decreases markedly with the increased pumping and it is felt that this type of measurement is indeed more indicative of the state of the melt. The gas content of both samples taken at various stages is given below.

	Oxygen, p.p.m.	Nitrogen, p.p.m.
After 1 min at 10^{-3} mm Hg	15	6
,, ,, ,, ,, 10^{-3} ,, ,,	20	7
,, 10 ,, ,, ,, ,, ,,	5	10
,, 30 ,, ,, ,, ,, ,,	5	4

Some further gas contents of vacuum-induction melted alloys are given in Table VI, and compared with vacuum-arc and air-melted alloys. The oxygen and nitrogen contents can both be reduced to about 20 p.p.m. or less.

Moore[6] shows that as the melt size of carbon–chrome ball steel (our alloy *C*) is increased from 250 lb to 2500 lb the oxygen content is reduced from 7 to 2 p.p.m.

Melt Size, lb	Average Oxygen Content, p.p.m.
250	7
700	5
2500	2

This may be compared with our value of 17 p.p.m. for a 20-lb melt.

Analysis of such small amounts is difficult and it is estimated that the values quoted are accurate only to ± 5 p.p.m. in the case of the authors' work using 10-g samples. The technique of vacuum fusion followed by the freeze-out method of gas analysis was used. If the sample weight is increased to 40 g the accuracy becomes ± 1 p.p.m. but this restricts the number of analyses which may be carried out on a vacuum-fusion furnace.

It should be mentioned that gas contents of the order illustrated are achieved only when the vacuum-induction heat is made from either 100% virgin-alloy charge or 100% vacuum-melted scrap. If, for example, a mixed scrap–virgin-alloy charge were used to make a steel containing substantial quantities of titanium, the oxygen present in the virgin alloy would be fixed by the titanium in the scrap as TiO_2 and this could only be reduced with difficulty.

Vacuum-induction melting is, therefore, best regarded as a purification of the base charge followed by an introduction of oxidizable or volatile elements or a re-melting of previously vacuum-melted scrap under inert conditions, minimizing the loss of volatile elements and preventing oxidation of reactive elements.

During the process there are significant reductions in many of the volatile trace elements but there is

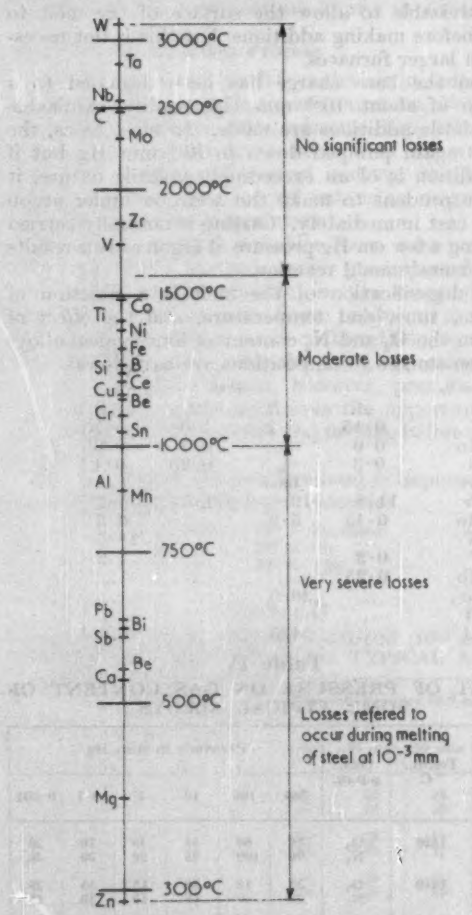

Fig. 9—Temperature for a vapour pressure of 10^{-3} mm Hg for some common elements

Table VI

COMPARISON OF THE AVERAGE* GAS CONTENT (p.p.m.) OF VARIOUS TYPES OF ALLOYS MADE BY DIFFERENT PROCESSES

Alloy Type	Air-melted basic electric process		Vacuum-induction process 10–20-lb melts		Vacuum-arc process	
	Oxygen	Nitrogen	Oxygen	Nitrogen	Oxygen	Nitrogen
1%Cr ball-race steel	20	88	14	40	9	52
12%Cr steels	40	430	22	78	16	135
Co-base casting alloy (X.40)	150	880	21	26	...	...
Ni-base alloy with high Al (G.64)	...	...	20	20	...	...
Ni-base alloys with Ti and Al additions (Nimonics)	26	132	30	24	15	20

* Average of at least five determinations

little quantitative data available on this aspect. It will be seen from Fig. 9 that many of the common residuals such as Zn, Pb, Bi, Cd, etc., are more volatile at steel-melting temperatures than manganese, an element which can readily be removed quantitatively.[7]

Bungardt and Sychrovsky[7] showed that C, Mn, Si, and Cu could all be reduced to very low levels by holding a pure iron melt for 2 h at 2×10^{-4} mm Hg.

	Original Iron, %	Sample after 2 h at 2×10^{-4} mm Hg, %
C	0·09	0·005
Mn	0·23	0·01
Si	0·16	<0·01
Cu	0·15	<0·03
S	0·009	0·008

These authors also showed that sulphur which was not removed by the simple vacuum treatment could be substantially reduced by a mischmetal (cerium) addition, 0·017%S being reduced to 0·006% by this treatment. No sulphur contents less than 0·005% are mentioned.

A further feature of the vacuum-induction process is close control of chemical composition. Moore,[6] and Darmara and Huntington,[8] have reported that Ti and Al contents can be controlled to $\pm 0{\cdot}12\%$ compared with practical limits of $\pm 0{\cdot}25\%$ for air-melting. These values refer to austenitic alloys containing several percent of Ti and Al. Even for small 12-lb melts the authors have had very satisfactory experience with these two reactive elements.

For about 30 melts containing from 1% to 3%Ti, the yield ranged from 85% to 100% with an average value of 95%. Similarly, for melts containing 6%Al, the yield ranged from 95% to 105% with an average value of 102%. These results apply to the melting procedures described above, i.e. the titanium was added after degassing the base and the melt was then outgassed at 10^{-3} mm Hg; the aluminium was added after degassing at 10^{-3} mm Hg, and the heat cast under a slight pressure of argon with no further vacuum treatment.

To illustrate the losses which occur during holding at low pressures, a complex heat was held under vacuum at 10^{-3} mm Hg and the analyses of progressive samples are shown in Table VII. There are substantial losses of Cr, Al, and particularly Mn (cf. Fig. 9). Carbon and titanium show a very small drop whilst all the other elements increase slightly owing to concentration.

Consumable-electrode Vacuum-arc Process

The electrodes for the consumable arc process may either be cast from a conventional air-melt or forged from a suitable air-melted ingot. The former process is to be preferred for economy but requires special cylindrical moulds of unusual length/diameter ratio. The electrodes must be suitably cleaned to remove all scale before vacuum-melting.

In the case of some of the very highly alloyed nickel-base alloys containing substantial quantities of Ti and Al, the production of a satisfactory electrode by air-melting may not be possible and in this case, the practice is to prepare the electrode by the vacuum-induction process. It will be appreciated that the control of chemical composition in the vacuum-arc

Table VII

ANALYSES OF COMPLEX VACUUM-INDUCTION HEAT HELD *IN VACUO*

Sample	Element, %											
	C	Mn	Si	Ni	Cr	Co	W	Mo	V	Al	Ti	B
As melted	0·29	1·03	0·61	10·18	9·32	9·30	1·91	1·84	0·97	0·58	1·80	0·0060
0·5 mm Hg	0·28	1·02	0·62	10·25	9·40	9·28	1·89	1·86	0·96	0·42	1·68	0·0062
10^{-3} mm Hg	0·28	0·71	0·62	10·19	9·36	9·30	1·90	1·94	0·97	0·33	1·65	0·0065
10^{-3} mm Hg (15 min)	0·29	0·12	0·62	10·43	9·08	9·48	1·98	1·98	1·01	0·30	1·68	0·0072
10^{-3} mm Hg (45 min)	0·27	0·02	0·65	10·88	8·52	9·70	2·05	2·03	1·00	0·27	1·70	0·0075

Fig. 10—Typical 2-ton arc-melted steel ingot at William Jessop and Sons, Ltd.

process is only as good as the control of composition during the preparation of the electrode.

The amperage used for melting depends on the ingot sizes and on the quality of the steel. For example, a 12-in. ingot will use a melting current of from 3000 to 10,000A, the lower amperages being preferred for alloys which are liable to segregate. Similarly, for 20-in. ingots, amperages of from 6000 to 18,000A. would be used. In both cases, the arc voltage would be between 23 and 26 V.

The ingot may be left to cool in the water-cooled copper crucible or in the case of large ingots of qualities liable to thermal cracking, it is preferable to remove the ingot as soon as possible and cool slowly either in insulating powder or a furnace. In some cases, the ingot surfaces are sufficiently good to permit direct forging but where lower amperages have been used, it may be necessary to turn the ingot to produce a satisfactory surface. A typical 2-ton ingot produced at the authors' plant is shown in Fig. 10.

In the vacuum-arc process the vacuum which is generally measured in the throat of the furnace (*see* Fig. 5) depends on (*a*) rate of melting, (*b*) capacity of pumping system and constriction of furnace, (*c*) gas content of electrode.

It is not possible to melt at a pre-selected pressure without altering one of these factors and the general practice is to use the highest vacuum possible which may range from 10^{-4} mm to 10^{-2} mm Hg.

Table IX

CREEP RUPTURE PROPERTIES OF EXPERIMENTAL HEATS OF UDIMET 500 ALLOYS
Tested at 11·2 tons/in² at 870° C (ref. [12])

B, wt-%	Zr, wt-%	Rupture duration, h	Elongation at rupture, %
0·0002	<0·01	45 52	2 2
0·0004	0·19	147 134	5 6
0·0089	<0·01	429 394	10 7
0·0088	0·01	666 627	17 12

Johnson[9] has shown that there is a critical pressure for cathode stability which increases with arc current. For example, with iron electrodes at 1600A this pressure is 0·5 mm Hg whereas at 600A it is only 0·03 mm Hg. Above this critical pressure no satisfactory arc operation is possible. There is always a pressure gradient between the space over the melt and the furnace throat and in general the pressure over the melt will be much higher than that actually measured. It is safest, therefore, to have as high a vacuum as possible in the throat and to use reasonably high amperages.

Arc instability will tend to be at a maximum when the power is reduced towards the end of the melt to hot-top the ingot and avoid excessive shrinkage cavities. Caution is therefore required at this stage of the melt.

From the work of Cobine and Burger[10] it would appear that the temperature of the metal bath immediately under the arc may be as high as 2700–4700° C. This very high temperature can facilitate thermal decomposition of stable nitrides and promote endothermic reactions.

As inclusions pass through the arc, if they are not chemically reduced, they are physically dispersed, and do not coalesce before being chilled in the melt. Dyrkacz, DeFries, and Pitler[11] have shown that light inclusions such as TiN and TiO_2 are levitated during the melt and concentrated at the ingot top. Due to the heat of the arc there is little danger of entrapment of any inclusions floating on the surface of the melt.

Volatile elements may be removed as in the induction process. Due to the shorter time period in which the metal is molten compared with the induction process, purification is not, in general, as complete as in the vacuum-induction process, although the short

Table VIII

PREFERRED VACUUM-MELTING PROCESS FOR VARIOUS CRITERIA
Cross indicates the preferred process

Criterion	Control of Composition	Lowest Gas Content	Cheapest Process	Ingot with Minimum Segregation and Central Porosity	No Refractory Inclusion	Large Ingot	Ease of Adding Reactive Element
Vacuum-induction	X	X					X
Vacuum-arc			X	X	X	X	
Vacuum-induction followed by vacuum-arc	X	X		X	X	X	X

Table X

COMPARISON OF AIR- AND VACUUM-MELTED NIMONIC 100 ALLOYS

Material	Duration at 7 tons/in² at 940° C, h	Elongation, %	Duration at 12 tons/in² at 870° C, h	Elongation, %	Duration at 6 tons/in² at 980° C, h	Elongation, %
Nimonic 100[11] air-melted	100	...	130	...	30	...
Jessop vacuum-melted W.1312 (0·015% B)	165	11	426	8	...	...
Jessop vacuum-melted W.1399 (0·015%B, 0·10%Zr)	622	5	822	5	177	18

time in which the metal is in the arc is compensated for to some extent by the very high prevailing temperatures.

It will be seen from Table VI that the gas content of vacuum-arc melted steel is similar to that of vacuum induction. If, however, the nitrogen content of the air-melted electrode is high, then it may not be reduced to a very low level. This applies particularly to high-chromium steels.

Owing to the dispersing effect of the arc it is common to find no inclusions larger than 0·0007 in. in, for example, bar material made from 12-in. ingots in carbon–chromium ball-race steel.

The consumable-electrode vacuum-arc process has two inherent advantages over the vacuum-induction process: (*a*) no refractory materials are used, (*b*) owing to the progressive freezing of the ingot, segregation and central porosity are minimized. The relative advantages of the consumable-electrode and the induction process are listed in Table VIII.

The Properties of Vacuum-melted Metal

From the discussion on the vacuum-induction and vacuum-arc process, it is apparent that vacuum-melted metal will be of higher quality in terms of freedom from non-metallic inclusions and lower residual element content than conventional air-melted material.

For some applications, particularly in the aircraft field, the highest quality material may be used irrespective of cost, but it is generally necessary to consider whether this extra quality is worth the cost for any particular application. At this stage in the development of vacuum metallurgy it is important to remember that costs will fall drastically, particularly with an expanding market, and any consideration of a new application should be made with this in mind.

Vacuum-melting will not always improve an alloy. For example, reducing the gas content of a titanium-hardened nickel-base high-temperature alloy may improve the ease of fabrication and the mechanical properties, but a similar reduction in gas content on mild steel or 18–8 niobium-stabilized steel will cause little or no improvement. Indeed, the 18–8 Nb steel may be weaker, particularly under creep conditions because of the removal of the strengthening nitrogen. This emphasizes that the advantages of vacuum-melting must be considered for each particular alloy type.

Vacuum induction capacity in the U.S.A. has been devoted mainly to the production of nickel-base alloys for gas turbine blades and carbon–chromium steel for bearings. The nickel-base alloys most widely used are Waspalloy,* M.252, and Udimet 500.[12]

With conventional air-induction melting, these alloys contain significant quantities of segregated TiO_2 and TiN. The presence of these inclusions makes the forging of the ingots exceedingly difficult and surface cracking and low yields are common. Vacuum-induction melting, by producing a cleaner product, gives much higher yields and also as the Ti and Al addition is then present as an effective alloying constituent, the high-temperature creep strength is improved.

Darmara and Huntington[8] have shown how the mean rupture life of Waspalloy has been increased by vacuum-melting. When tested at 14½ tons/in² at 815° C the average duration of 100 air-melts was 100 h. The average duration of 100 vacuum-melts was 260 h and improvements in vacuum-melting techniques increased the average duration of 40 later heats to 350 h.

It was found that by vacuum-melting, such reactive trace additions as boron and zirconium could be readily controlled and still further improvements made in the creep rupture strength. The magnitude of these effects is shown in Table IX taken from the work of Decker, Rowe and Freeman.[13] These results indicate an improvement in the 100-h rupture strength of about 50% associated with a remarkable improvement in ductility.

Vacuum melting also enables the normal deoxidants Mn and Si to be held to a minimum and it has been shown by Bungardt and Sychrovsky[7] and others, that these elements impair the creep rupture properties of this type of alloy.

The hot workability of these materials is improved to such an extent by vacuum-induction melting that the Ti and Al contents may be increased beyond the limits practicable for air-melting, with further improvements in creep strength.

Although there has been no production experience of vacuum-melted alloys of this type in the U.K., the authors have made many experimental alloys in the 20-lb laboratory furnaces. These have confirmed the U.S. experience in that fabrication has been made easier and the modifications to composition facilitated by vacuum-melting have resulted in improved rupture strength and ductility. For example, the Nimonic 80A alloy[14] has a 300-h rupture strength at 750° C of 14·8 tons/in² and a ductility of about 2%. A vacuum-melted alloy to the same specification had a rupture strength of 19·5 tons/in² with 6½% elongation.

Some similar results for Nimonic 100 alloys are given in Table X. The alloys tested in the vacuum-

* *See* Table XIX, p. 430.

Table XI

FATIGUE STRENGTH OF 1%C–Cr STEEL MADE BY DIFFERENT PROCESSES

Process	Source of Data	Fatigue Strength, ± tons/in²	
		20×10^6 reversals	100×10^6 reversals
Basic electric	Moore	43	39
	Frith (1)*	40½	38
	Authors (8)	46	38½
Acid open-hearth	Frith (2)	51	44½
	Authors (2)	54½	...
Neutral open-hearth	Frith (1)	58	51
Acid high-frequency	Frith (2)	46½	41
Vacuum-induction	Moore	63	58
	Authors (1)	59	53
Vacuum-arc using basic electric electrode	Authors (3)	52	48
Vacuum-arc using acid open-hearth electrode	Authors (2)	62	58

* In brackets, number of heats

melted condition by the authors had the compositions given below and may be contrasted with the Nimonic 100[14] specification:

	Nimonic 100, %	W.1312, %	W.1399, %
C	0·3 max.	0·25	0·25
Mn	...	0·01	0·01
Si	0·5 max.	0·08	0·08
Cr	10–12	11	12·5
Co	18–22	19	19
Ti	1·0–2·0	1·3	1·2
Al	4·5–5·5	5·2	5·2
B	not mentioned	0·015	0·015
Zr	not mentioned	...	0·1

The vacuum-melted alloy, W.1399, containing controlled additions of B and Zr, had a rupture strength at 940° C, 55% greater than the air-melted alloy normally produced. At 980° C the improvement in rupture strength was 70%.

For materials of the type discussed, it is preferable to vacuum-induction melt as air-melted electrodes required for the vacuum-arc process cannot be readily melted to the close chemical specification required for alloys of this type. Where it is essential to have large ingots free from segregation and central looseness, it is necessary to use electrodes made by the vacuum-induction process for subsequent re-melting by vacuum-arc process. This has already become a production process in the U.S.A.

The second most widely used vacuum-induction melted material is the well known carbon–chromium ball-race steel. The steel should be free from non-metallic inclusions and should have good carbide distribution to achieve the best results in ball races. So far this material has been made by both the vacuum processes and further evaluation is necessary to decide which is to be preferred. The vacuum-induction process enables carefully selected raw materials to be used with a low sulphur-content, an essential feature if the steel is to be free from non-metallic inclusions. The consumable-electrode process can, however, be made to a low sulphur-content provided the electrode is made by the basic electric process and special precautions are taken.

Rejections of material for ball races may be due to outcropping inclusions which in the case of very small races may be as small as 0·0003 in. For such stringent applications as this it is apparent that even the dispersing effect of the arc in the consumable-electrode process may not be sufficient and that very low total non-metallic contents must be the aim. The present evidence suggests that the vacuum-induction furnace is better suited to this requirement but is the more expensive process.

Much work remains to be done on the testing of bearings under actual service conditions and comparing material made by both the processes. From work done in the U.S.A.,[15] it would appear that both vacuum-arc and induction material have been shown to have an improved bearing life. In particular, it is found that the percentage of bearings failing at low durations is decreased by vacuum-induction melting and hence the overall rating of the bearing increased.

A considerable amount of work has been done in the U.K. by Frith[16] on the fatigue properties of ball-race steels, although opinions vary on how this is related to actual bearing performance. Frith has shown that so-called 'neutral open-hearth' material can have a fatigue limit of up to ± 51 tons/in² based on 100×10^6 reversals. Some of his results are summarized in Table XII and equivalent results for basic electric and acid O.H. steel are ± 38 and ± 44 tons/in² respectively. These results are confirmed by the authors' results also shown in Table XII. Results due to Moore[17] indicate that vacuum-induction melting raises this fatigue limit to ± 58 tons/in².

Vacuum-induction material from 20-lb ingots gave somewhat lower results (± 53 tons/in²) in the authors' experience, and the results from consumable-arc material using electrodes made from basic electric material were lower still (± 48 tons/in²). Much improved fatigue strength occurred when acid O.H. material was used for the vacuum-arc process as ± 58 tons/in² was obtained.

It is important to stress, however, that the vacuum-arc material from acid O.H. stock is dirty by normal vacuum-melted standards as it contains 0·02%S and hence many dispersed manganese sulphide inclusions.

This emphasizes how important the inclusion

Table XII

TENSILE PROPERTIES OF 25-in. DISC FORGING FROM A CONSUMABLE-ELECTRODE VACUUM-ARC MELT OF G.56

Position No. (see Fig. 11)	Direction	U.T.S., tons/in²	0·1% P.S., tons/in²	El %, $4\sqrt{A}$	R. of A., %
1	Axial centre	53·4	...	7·5	5·0
2	,, ,,	62·6	...	16·0	12·0
3	,, ,,	65·6	...	21·5	23·0
4	,, ,,	59·6	41·0	11·0	14·0
5	,, medial	57·7	39·5	10·5	17·0
6	,, ,,	58·5	41·9	10·5	17·0
7	,, periphery	58·0	...	10·0	8·0
8	Radial ,,	66·2	42·0	24·0	31·0
9	Tangential centre	61·1	41·0	18·0	17·0
10	,, ,,	61·4	41·0	16·5	24·0
11	,, ,,	61·2	40·5	16·5	24·0
12	,, ,,	64·2	42·0	16·5	24·0
13	,, ,,	64·7	42·2	24·0	31·0
14	,, ,,	63·7	41·7	19·5	27·5
15	,, ,,	61·9	42·2	13·0	24·0
16	,, periphery	64·2	39·5	21·0	24·8
17	,, ,,	65·0	40·25	21·0	24·8

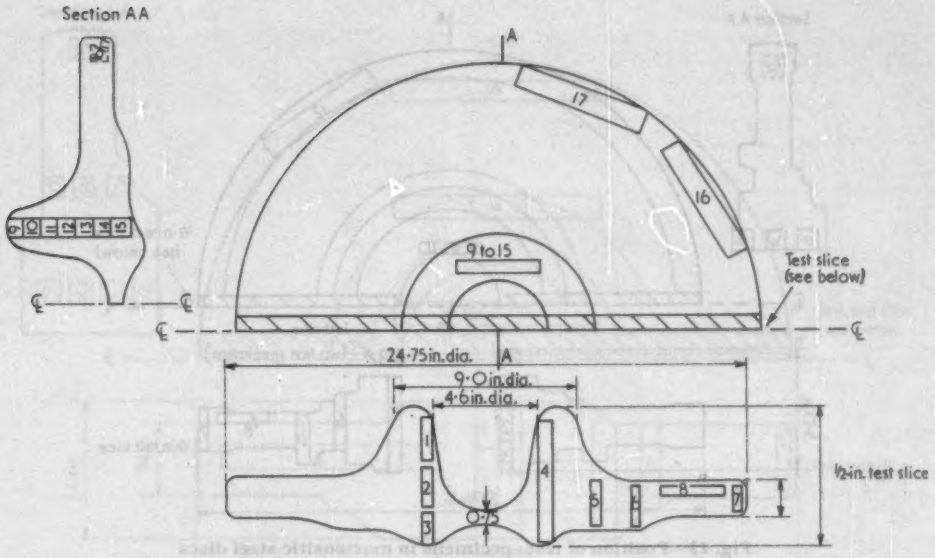

Fig. 11—Position of test specimens in G.56 Vacumelt disc

is in promoting fatigue failure as it is obviously the finely dispersed inclusions remaining after vacuum-arc melting which are responsible for initiating fatigue failure and not the massive sulphides (Frith[16]). That the earlier history of the steel electrode should still influence the fatigue properties is of considerable interest and importance.

The main production of vacuum-arc melted material in the U.S.A. has been austenitic disc materials such as A.286.[11] Like the nickel-base alloys for turbine blades, these alloys are strengthened by additions of Ti and difficulty is experienced in forging air-melted material owing to TiO_2 and TiN inclusions. It has been found that for this class of alloy, electrodes can be air-melted and the subsequent consumable-arc melting yields an ingot with satisfactory fabrication properties.

The authors have experience of a similar British alloy, G.56, melted to the following specification:

	Element, %		
C	0·1 max.	Cr	14
Mn	1·0	Mo	2·5
Si	0·7	Ti	1·8
Ni	23	Nb (plus Ta)	0·4

A 20-in. ingot made to this specification by consumable-electrode melting was press-forged to a bloom of suitable diameter and subsequently upset by drop stamping to a disc about 25-in. dia. To evaluate the mechanical properties of this disc, test pieces were taken from the various positions shown in Fig. 11 and tensile tests carried out at 20° C (Table XII). It will be seen that consistent mechanical properties are obtained throughout the disc and that ductilities in excess of 10% are achieved except in one instance with an axial centre test which gave a value of 7½%.

In the U.K. such materials have only recently become of interest and most gas turbines have used 11%Cr martensitic steel discs. Consequently the authors have studied the production of discs of this type by vacuum-arc melting. It has been found possible by air-melting to achieve satisfactory combinations of a creep strength and room-temperature mechanical properties including adequate transverse ductility at the centre of the discs using 11%Cr steels of the kind H.46.[18] However, the standard of cleanness demanded by the British aircraft industry for jet-engine components becomes increasingly higher and is reaching the stage when the conventional basic electric process cannot meet the demand without excessive rejections. For example, discs may be rejected for some applications if inclusions greater than 0·030 in. are found by immersion ultrasonic examination anywhere in the body of the disc or if an inclusion of any size is found on the surface of the disc in a critical location.

Consequently the vacuum-melting of this kind of alloy is required for cleanness alone and may ultimately pay for itself in terms of lower scrap-rate.

Also, when efforts were made to improve these steels to give still higher creep strength, it was found that it became increasingly difficult to obtain adequate transverse ductility. One such experimental alloy in which discs were made was a steel to the analysis below:

	Element, %		
C	0·08	Co	10
Mn	0·9	Mo	1·1
Si	0·2	Nb	0·4
Cr	10	Ni	0·2
W	0·85	V	0·47

Discs of 25-in. dia. were made from 20-in. vacuum-arc ingots of this quality and also from conventional 18½-in. ingots of air-melted material. These were sectioned as shown in Fig. 12 and extensive tests carried out to determine the mechanical properties in both melted conditions and the results are compared in Table XIII. It will be seen that the vacuum-melted material has improved ductility in the case of

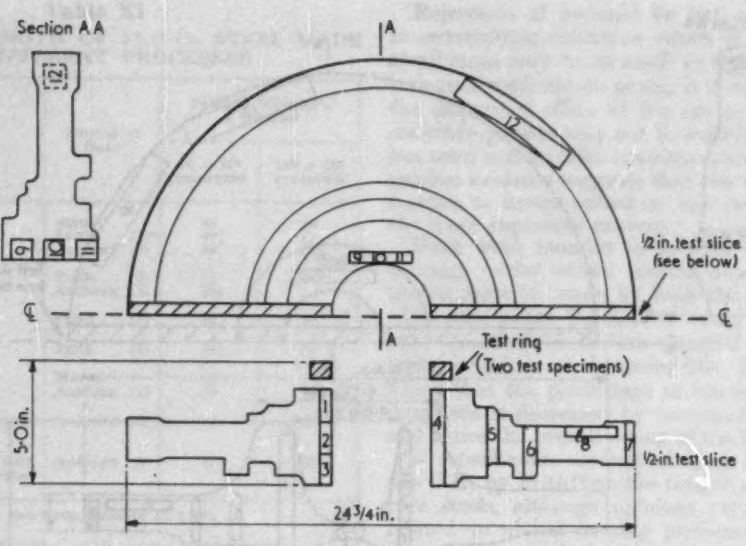

Fig. 12—Position of test specimens in martensitic steel discs

axial tests at the centre of the disc. For example, in position 4, the elongation was 4½% for air-melted and 15·6% for vacuum-melted material.

It is perhaps worthwhile re-emphasizing that the advantages in vacuum-melting this steel are to achieve improved cleanness, and mechanical properties, and minimize rejections, and not to improve creep strength and ease of fabrication as in the case of the A.286 and G.56 types.

It was apparent during much of the early development work on disc forgings in the U.S.A. and the U.K. that the accepted minimum forging reductions used in cogging ingots to blooms before upsetting into discs could be reduced in the case of consumable-electrode arc-melted material. Indeed, earlier experience in the U.S.A. on the Kellogg process had shown that even when the consumable-electrode process is carried out in air, the improved structure in the resulting ingot enables forging reductions to be reduced.

An experiment was carried out using a 9-in. as-cast ingot of G.18B which has the following composition:

Element, %			
C	0·4	Co	10
Mn	0·8	W	2½
Si	1·0	Mo	2
Ni	13	Nb	3
Cr	13		

It was found possible to upset this ingot satisfactorily to a 14½-in. dia. disc which was sectioned as shown in Fig. 13. The results are given in Table XIV. It will be seen that in general the ductility figures achieved throughout this forging are excellent although the test carried out in the lower portion of the centre of the disc has a borderline ductility of 9%.

When it is considered, however, that a substantial forging reduction is normally accepted as essential for air-melted and conventionally cast ingots, it is apparent that the improved ingot soundness achieved by consumable-electrode melting can offer scope for further developments in the manufacture of intricate forgings.

Table XIII

COMPARISON OF PROPERTIES OF DISC FORGINGS IN AIR- AND VACUUM-ARC MELTED 10·5% Cr MARTENSITIC STEEL

Test-piece Position (see Fig. 12)		Air Melted				Vacuum Melted			
		0·1% P.S., tons/in²	U.T.S., tons/in²	El. %, $4\sqrt{A}$	R. of A., %	0·1% P.S., tons/in²	U.T.S., tons/in²	El. %, $4\sqrt{A}$	R. of A., %
Axial hub	1	...	84·4	18·0	57·0	...	82·2	17·5	56·0
,, ,,	2	...	82·6	9·0	15·0	...	81·6	13·0	43·0
,, ,,	3	...	84·8	15·0	45·0	...	82·8	18·0	50·0
,, ,,	4	...	81·8	4·5	6·5	...	81·8	15·6	52·5
Axial near hub	5	...	81·7	11·1	21·0	...	81·6	14·3	43·5
,, midway	6	...	83·4	14·2	40·0	...	83·6	16·0	43·0
,, periphery	7	...	81·3	14·5	50·0	...	82·0	18·0	54·0
Radial periphery	8	...	82·0	20·0	60·0	61·0	81·7	17·0	57·5
Transverse hub	9	...	83·7	16·0	52·0	...	80·6	17·0	60·0
,, ,,	10	...	81·8	18·0	60·0	...	80·4	18·5	60·0
,, ,,	11	...	81·6	18·0	60·0	...	82·4	17·0	55·0
,, periphery	12	62·5	82·3	19·0	59·6	65·0	81·5	18·5	52·4
Transverse hub	Test ring	60·0	82·2	18·0	58·0	...	80·7	15·0	40·5
,, ,,	,, ,,	58·0	81·9	18·6	55·0	...	79·5	18·0	57·5
,, ,,	,, ,,	...	...	...	...	62·3	79·9	15·5	43·5

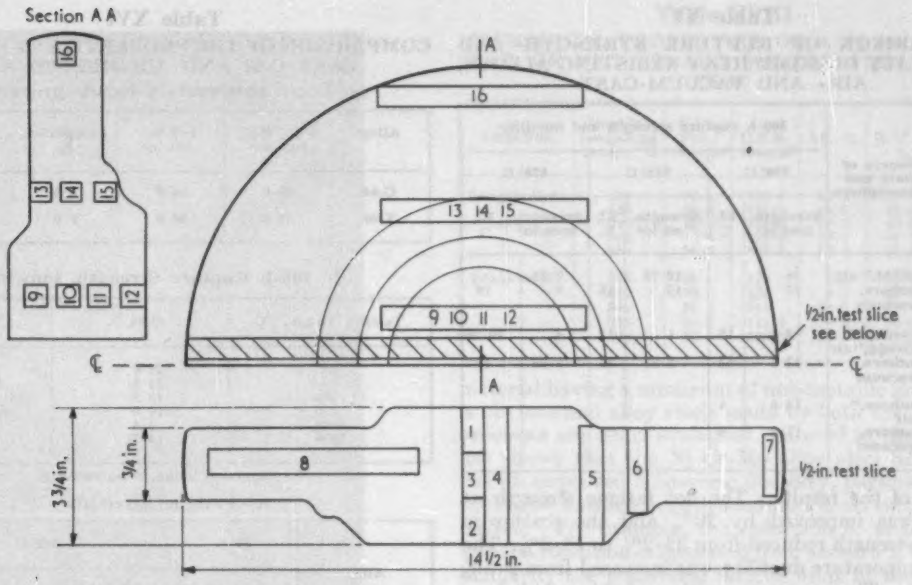

Fig. 13—Positions of test pieces from vacuum-melted G.18B disc (directly upset from the ingot)

Apart from the major production applications discussed, vacuum-melting is being considered both in the U.S.A. and in the U.K. for many other applications.

The precision-casting industry has been troubled in the past by the difficulty of casting some of the heat-resisting alloys containing Ti and Al. Not only have significant losses of these elements occurred in remelting, but the oxidation products TiO_2 and Al_2O_3 have caused dirty castings and high rejection rates. It has been found that the ideal process for these materials is to prepare vacuum-melted stock by casting suitable-diameter bar in steel or cast-iron moulds in a large vacuum-induction furnace and to remelt this in a small vacuum-induction furnace specially designed to receive one or more of the hot moulds normally used with the lost-wax process. The whole melting and casting process must be rapid to avoid temperature drop of these moulds. Alternatively, they may be introduced through a mould lock immediately before casting.

Table XIV

PROPERTIES OF VACUUM-MELTED G.18B DISC DIRECTLY UPSET FROM INGOT

Test-piece position (see Fig. 13)		0·1% P.S., tons/in²	U.T.S., tons/in²	El, %	R. of A., %
Axial centre	1	...	38·0	14·0	9·0
,, ,,	2	...	34·8	...	...
,, ,,	3	...	39·2	15·0	11·0
Axial midway	6	19·0	41·2	33·5	17·0
,, periphery	7	...	40·8	19·0	10·0
Radial	8	15·0	43·9	44·5	47·1
Transverse centre	9	13·1	40·4	19·0	47·1
,, ,,	10	13·5	43·6	37·0	35·7
,, ,,	11	14·0	37·4	14·0	19·0
,, ,,	12	14·2	33·6	9·0	21·0
Transverse midway	13	14·0	43·4	40·0	39·7
,, ,,	14	13·5	43·9	44·0	47·1
,, ,,	15	13·6	44·0	46·0	47·1
,, periphery	16	13·9	44·0	35·0	35·7

There are several possible variations of this process, such as casting vacuum-melted stock under a protective atmosphere of argon, which may be suitable in special cases. It is apparent from the work of Hammond and Flinn[19] on GMR.235, Guy alloy, and Inco 700 nickel-base casting alloys, that the ideal, as far as creep strength and ductility are concerned, is vacuum-casting of vacuum-melted stock.

While there was only minor improvements in the creep rupture strength compared with air-casting, vacuum-melted material showed a pronounced improvement in rupture ductility as shown below.

Alloy	Rupture Ductility	
	Air-cast	Vacuum-cast
GMR.235	6–9	14–19
Inco 700	2–4	21
Guy Alloy	3	7–10

By further alloying it is possible to translate this improved ductility into better rupture strength at reduced ductility.

Several nickel-base casting alloys including GMR. 235 and Inco 713 are now being vacuum-cast commercially in the U.S.A.

The authors have evaluated the properties, as-vacuum-cast, of several heat-resisting alloys not containing titanium or aluminium, and compared the rupture strength with published data on air-melted material[20, 21] (*see* Table XV). Improvements in rupture strength of the order of 10%–25% were achieved by vacuum-melting, and there were also substantial improvements in rupture ductility in some instances. It should be pointed out, however, that the casting technique used by the authors for the vacuum-melted material may not be identical with that used for the air-melted material.

With G.34[22] however, the slight improvement in rupture strength on vacuum-casting was accompanied by decrease in scatter of 100-h rupture strength from $\pm$ 14·3% to $\pm$ 8·1% based on $\pm$ 3 sigma, i.e.

Table XV

COMPARISON OF RUPTURE STRENGTH AND DUCTILITY OF SOME HEAT RESISTING ALLOYS, AIR- AND VACUUM-CAST

Alloy	Source of Data and Atmosphere	300-h rupture strength and ductility					
		750° C		815° C		870° C	
		Strength, tons/in²	El, %	Strength, tons/in²	El, %	Strength, tons/in²	El, %
X.40	ASTM,[10] air	16		10·75		7·75	
	Authors, vacuum	17		12	15	9	19
C.242	Wood and Gregg,[21] air	9·5	18	6	12	4	10–20
	Authors, vacuum	12·5	43	8·75	48	6·75	41
G.34	Authors,[21] air	15·6	6				
	Authors, vacuum	17·3	6				

99·8% of the results. The hot fatigue strength at 750° C was improved by 20% and the scatter in fatigue strength reduced from 33·2% to 18·2%. The room-temperature ductility was increased from 2·5% to 9·5%. Thus vacuum-melting of this cobalt-base alloy, containing no Ti, Al, or other reactive element, was beneficial.

Such effects are to be expected owing to the freedom of vacuum-cast metal from gaseous impurities which can cause micro-porosity and to the improved cleanness.

The authors have developed a 6%Al, Ni-base alloy (G.64) only suited for vacuum-casting. The properties of this alloy are summarized in Table XVI and compared with X.40. This alloy has been selected for comparison as it is the most extensively used air-cast high-temperature alloy in the U.S.A.

The composition of G.64 has been chosen to obtain the best rupture strength compatible with sufficient cold ductility, i.e. about 4%. Comparison of the results in Table XVI show that this has been achieved but that G.64 has somewhat lower fatigue strength than X.40. This is due to the presence, in the microstructure of G.64, of substantial quantities of inter-

Table XVI

COMPARISON OF THE PROPERTIES OF VACUUM-CAST G.64 AND AIR-MELTED X.40

(a) Room temperature tensile properties

Alloy	0·1% P.S., tons/in²	U.T.S., tons/in²	Elongation, %	R. of A., %
G.64	40·0	55·0	4·0	5·0
X.40	35·0	50·0	8·0	8·0

(b) 100-h Rupture Strength, tons/in²

Testing Temp., ° C	G.64	X.40
800	29·0	12·0
850	22·5	10·0
900	15·5	8·0
950	10·0	6·5
1000	6·4	5·5
1050	(4·2)	3·7

Extrapolated value in parenthesis

(c) Fatigue Strength

Alloy	20° C	800° C	
	40×10^6 Reversals	40×10^6 Reversals	100×10^6 Reversals
G.64	±19	18½	±17
X.40	±24·1	...	±20·7

granular phase, which cause improved rupture strength at the expense of cold ductility and fatigue strength. The notched fatigue strength, which is of perhaps greater practical importance, would not be expected to be lower than that of X.40.

Where ease of fabrication is all-important as in the production of high-temperature strength sheet materials, vacuum-induction melting has been used. For example, considerable quantities of vacuum-melted GMR.235, originally developed as a casting alloy,[20] have been made as sheet, and the improved cleanness has proved essential.

In the growing field of ultra-high-tensile steels for aircraft applications, the value of high-ductility

Table XVII

TENSILE PROPERTIES OF ULTRA-HIGH-TENSILE STEEL

Material	Location	Proof Stress, tons/in²			Maximum Stress, tons/in²	Elongation, %	R. of A., %	Izod, ft-lb
		0·05	0·1	0·2				
8-in. bloom, vacuum-melted	Transverse axis	92·4	100·6	108·6	132·0	6·0	15·0	9
		97·6	103·8	110·0	133·0	7·0	20·0	10
	Transverse surface	91·0	100·0	108·4	132·0	7·0	20·0	11
		91·0	100·0	107·8	131·5	7·0	20·0	11
	Longitudinal axis	92·2	100·0	106·8	129·0	7·5	25·0	14
		92·2	100·0	107·6	129·5	6·0	25·0	15
	Longitudinal surface	94·0	102·0	108·8	132·0	7·5	25·0	15
		94·0	102·8	109·4	132·5	7·0	20·0	15
4-in. bloom, air-melted	Transverse axis	...	102·5	...	127·4	4·4	9·6	6
	Transverse surface	...	98	...	127	4·4	9·6	3
	Longitudinal axis	...	95	...	123	9·0	27·6	10
	Longitudinal surface	...	95	...	125·4	9·5	27·6	11

Fig. 14—Typical section of a 9-in. consumable-electrode melt of 18–4–1 high-speed steel

Table XVIII

MECHANICAL PROPERTIES OF A 7½ in. × 1½ in. SLAB OF VACUUM-ARC MELTED 5%Cr STEEL (H.50)

Direction	Double-tempering temp., °C	0·1% P.S., tons/in²	U.T.S., tons/in²	El., %	R. of A., %	Izod, ft-lb
Longitudinal	520	90·5	133·0	12·3	33·9	6
	540	96·0	123·0	13·1	45·0	9
	560	98·0	124·0	13·9	45·0	11
	580	96·0	122·0	13·1	47·1	13
	600	90·5	109·5	12·3	47·1	11
Transverse	520	88	128	9·1	29·4	6
	540	95	124	8·3	26·9	6
	560	88·5	115	11·5	47·1	6
	580	95·7	122·3	9·0	30·0	7
	600	87·0	105·5	12·3	42·8	9

material having a minimum of non-metallic inclusions is obvious and alloy steels made by both the vacuum processes are being evaluated. Moore[6] in the U.S.A. has shown that the Ni–Cr–Mo alloy steel SAE.4340 has an improved transverse ductility, particularly in the higher tensile-strength condition when vacuum-arc melted. For example, the reduction of area in the 120-ton condition is increased from about 6% to 18%. Similarly, the transverse fatigue limit in the 85-ton condition was increased from 26 tons to 39 tons by consumable-electrode melting.

Similar results on SAE 4340 for vacuum-induction material showed that in the 100-ton condition, vacuum-melted material had a fatigue strength of 47 and 51 tons/in² in the transverse and longitudinal directions respectively, whilst even the longitudinal direction fatigue-strength of the air-melted material was only 40 tons/in².

The authors have evaluated the tensile properties of an 8-in. bloom forged from a 20-in. vacuum-arc ingot of the composition:

	Element, %		
C	0·38	Ni	0·55
Mn	1·07	Cr	1·63
Si	2·07	Mo	0·52
S	0·014	V	0·30
P	0·015		

The results of tensile and impact tests in the 130-ton condition obtained by oil-quenching at 860° C and tempering for 5 h at 300° C are given in Table XVII. The properties are exceedingly uniform throughout the bloom. For comparison, results are also given for a 4-in. bloom of air-melted material.

There is considerable interest in the use of 5%Cr steels (H.50) for high-tensile applications owing to the higher tempering temperatures which may be used with these steels and the consequent effective stress relief. The authors have evaluated a 7½ in. × 1½ in. slab forged from a 12-in. vacuum-arc ingot. The tensile and impact properties of this slab air-hardened at 1000° C, and with different tempering treatments are given in Table XVIII. The ductilities and impact values in the transverse direction compare favourably with those in the longitudinal direction for an alloy steel of this type.

A logical development in this field will be the production of vacuum castings in ultra-high-tensile steels where the increased fidelity of the clean, gas-free steel will ensure a more reliable product. Even without an improvement in mechanical properties,

Table XIX
COMPOSITION OF ALLOYS DISCUSSED

Alloy	Element, %													
	C	Mn	Si	Ni	Co	Cr	W	Mo	V	Nb	Ti	Al	B	Fe
Carbon chromium ball race steel	1·0	0·5	0·25			1·5								base
Waspalloy	0·07	0·7	0·4	base	14	19		4·3			3·0	1·3		1 max
M.252	0·15	0·5	0·5	base	10	19		10·0			2·5	1·0		2 max
Udimet 500	0·08	0·75 max	0·75 max	base	19	19		4			2·9	2·9		4 max
Ni.90A	0·1 max	1·0 max	1·0 max	base		20					2·3	1·3		5 max
Ni.100	0·3 max		0·5 max	base	20	11		5			1·5	5·0		2 max
A.286	0·05	1·35	0·5	26		15		1·25	0·3		2·0			base
H.46	0·15	0·8	0·3			11·8		0·45	0·3	0·25				base
G.18B	0·4	0·8	1·0	13	10	13	2·5	2·0		3·0				base
GMR.235	0·15	0·5	0·5	base		19		5·2			2·0	3·0	0·06	10
Guy alloy	0·1			base		13		6		2·0		6·0	0·5	4·5
Inco 700	0·13	0·08	0·25	46	29	15		3·0			2·2	3·2		0·8
Inco 713	0·12	0·15	0·4	base		13		4·5		2·25	0·6	6·0		1·0
G.34	0·8	1·0	0·3	12	45	20		20	2·8	1·2				remainder
G.64	0·12	0·4	0·4	base		10	4·0	3·0		2·0		6·0	0·3	5 max
X.40	0·5	0·5	0·5	10	base	25	8·0							1·5
C.242	0·3	0·3	0·3	base	10	20		10			0·3 max	0·2 max		1 max
SAE.4340	0·4	0·75	0·3	1·8		0·8		0·25						base
H.50	0·37	0·5	1·10			5·0		1·35	1·1					base
SAE.446	0·35 max	1·5 max	1·0 max			25								base

the avoidance of inclusions at fillets or changes of sections would justify the use of vacuum-casting for some applications such as aircraft parts.

Vacuum arc-melted tool steels are already being used in the U.S.A. for bearings and vacuum-melted 18–4–1 is being evaluated in the U.K. The reason is that the superior cleanness will give better bearing life and there is also the possibility that the improved ingot freezing-characteristics of the vacuum-arc process will result in sounder ingots with less carbide segregate. The macrostructure of a 9-in. vacuum arc-melt of 18–4–1 made at the authors' works is shown in Fig. 14 and it will be seen that there are no coarse carbide segregates.

Moore[6] has shown that the impact strength of some steels may be improved by vacuum-induction melting. Notably, the Charpy value for 25%Cr steel (SAE.446) at 20° C was increased from 5 to 135 ft-lb owing to changing the impact transition temperature from above 20° C to below.

The ability to produce very low-carbon stainless steel by vacuum-induction melting has been of interest in the U.S.A. for atomic-energy applications where corrosion resistance and freedom from embrittlement must be of the highest order. The use of vacuum-induction melting also enables manganese, an undesirable element in material for reactor construction, to be kept below 0·02%, and other harmful impurities such as cobalt to be carefully controlled. There is growing interest in this class of material in the U.K.

Finally, where close control of chemical composition and freedom from gaseous and other impurities are important as in high-permeability alloys, controlled expansion alloys for glass-to-metal seals, etc., use is being made of vacuum-induction melting.

Future Developments

It is believed by some authorities that there may be a practical limit to the size of vacuum-induction furnaces at about 2–3 tons, due to electrical and crucible problems at larger sizes. For the applications being considered at present, this size limit should offer no technical restrictions, although it might ultimately prevent the cost of bulk vacuum-melted products being reduced. No such size limitations are foreseen for vacuum-arc furnaces and it is considered that 40–50-in. dia. furnaces melting 15–20 tons of steel are a practical possibility today.

There is also a growing interest in two new processes: *Skull Melting*—In this process a consumable-steel electrode would be melted *in vacuo* into a shallow copper hearth, held molten under argon by non-consumable tungsten or graphite electrodes, whilst bath samples were taken and further alloy additions were made, and finally cast by lip-pouring into conventional ingot moulds. A skull of the alloy would be left in the furnace owing to the chilling effect of the copper hearth. By this method, some of the advantages of both processes would be obtained.
Electron-bombardment Melting—With this process, a steel electrode would be melted using electron bombardment from a high-voltage (15,000 V) tungsten source under very high vacuum (10^{-4} mm Hg). The molten metal would be collected in a water-cooled hearth and the surface of the melt heated from a similar electron source. This facilitates further purification. The process is costly owing to the electrical equipment required and the high vacuum necessary to stabilize the electron emission. It has been shown to offer opportunities for a higher degree of purification than other processes, but consequently cannot melt alloys containing volatile constituents.

Despite the challenge of these newer processes, it is clear that vacuum-induction and consumable-electrode vacuum-arc melting will account for the bulk of production capacity for many years to come.

CONCLUSIONS

Vacuum-melting both by the induction and the consumable-electrode arc process have proved their ability in the production of extra high quality material mainly for aircraft and similar applications. With the growth and consequent reduction in cost of production, there is every likelihood that suitable applications will arise in other fields. Wherever the

cost of a finished product is high relative to the cost of the material, as in complicated dies and broaches for example, it is clear that by minimizing rejections one could pay for vacuum-melting. In such cases, and where high material fidelity is essential, vacuum melting should find many outlets.

Acknowledgments

The authors wish to express their thanks to Messrs. W. H. Bailey, E. Johnson, and R. Hall and their other colleagues who have been responsible for much of the experimental work reported.

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Forthcoming Conferences and Exhibitions

Symposium on Instrumentation and Computation

The joint symposium on instrumentation and computation in process development and plant design, organized by the Institution of Chemical Engineers, the Society of Instrument Technology, and the British Computer Society (*J.I.S.I.*, 1958, Oct., p. 196), is to be held at The Central Hall, Westminster, S.W.1, on 11th–13th May, 1959. Enquiries should be sent to the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

Corrosion Exhibition, 1959

The 1959 Corrosion Exhibition is to be held at the Royal Horticultural Society's New Hall, Westminster, from 27th to 30th April. Details may be obtained from the Exhibition Organiser, "Corrosion Technology," Leonard Hill House, Eden Street, London, N.W.1.

International Federation of Automatic Control

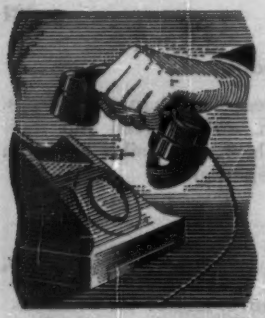
The first International Congress of the International Federation of Automatic Control (IFAC) is to be held in Moscow from 25th June to 5th July, 1960. The Congress will cover three fields—theoretical and experimental investigations on automatic control and servomechanisms, instrumentation and investigations connected with the development of automatic control systems, and industrial applications of automatic control (including the application of prediction and computing devices). Papers are invited from the U.K. for presentation at the Congress. Intending authors should submit abstracts of not more than 500 words to Mr. W. Bamford, Honorary Secretary, Group B, British Group for Computation and Automatic Control, c/o The Institution of Electrical Engineers, Savoy Place, London, W.C.2, by not later than 1st February, 1959.

Conference on Fracture

A seminar on the atomic mechanisms of fracture is to be held at Cambridge, Mass., from 12th to 14th April, 1959. It is being sponsored by the National Science Foundation, the Office of Naval Research, the Air Force Office of Scientific Research, and the National Academy of Sciences–National Research Council. Papers to be presented will cover theoretical aspects of fracture, cleavage, crystalline and non-crystalline fracture, fatigue and ductile fracture, and high-temperature fracture. Further details may be obtained from Dr. B. L. Averbach (*Chairman*) or Dr. D. K. Felbeck (*Secretary*), Conference on Fracture, National Academy of Sciences—National Research Council, Washington, D.C., U.S.A.

Conference on Chipless Forming

The Metal Working Division of the Polish Association of Mechanical Engineers is organizing a conference on chipless forming of metals and plastics, to be held in Poznań in June, 1959, during the 28th International Fair. The subjects to be covered are: practical aspects of the theory of plasticity and theoretical bases of forming processes; technology of cold and hot-working processes; plant and instrumentation; economic aspects; and the historical development of the process. Papers are invited on these subjects; all correspondence should be sent to Professor F. Tychowski. Pl. Curie-Sklodowskiej 5, Poznań, Poland.



N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Autumn General Meeting, 1958

The Autumn General Meeting of the Institute is being held in London on Wednesday, **10th December.** After the formal business, which begins at 10 a.m. at **Caxton Hall, London S.W.1** (NOT at the Offices of the Institute, as announced earlier) there will be two simultaneous technical sessions during the morning. One, on continuous casting, will be held at **Caxton Hall,** and the other, on creep, at the Institution of Naval Architects, 10 Upper Belgrave Street, London, S.W.1. During the afternoon, the meeting on continuous casting will continue, and there will also be a joint meeting with The Institute of Welding on hydrogen in weld metal at the Institution of Naval Architects.

Full details of the programme appeared in the November issue of the *Journal* (p. 312).

11th Hatfield Memorial Lecture

Dr. N. P. Allen, F.R.S., Superintendent of the Metallurgy Division, National Physical Laboratory, will deliver the Eleventh Hatfield Memorial Lecture at 6 p.m. on Tuesday, **9th December,** at the Weir Lecture Hall, Institution of Naval Architects, 10 Upper Belgrave Street, London, S.W.1. The subject of his lecture will be "The Mechanical Properties of the Ferrite Crystal."

NEWS OF MEMBERS

Dr. **P. T. Arthur** has left Hadfields Ltd. to take up an appointment with the Park Gate Iron and Steel Co., Ltd.

Mr. **P. R. Bancroft** has taken up a post with the Ministry of Supply at Birtley, Co. Durham.

Mr. **A. S. C. Blench** has taken up an appointment with Henry Wiggin and Co., Ltd.

Mr. **G. J. N. Cherry** has joined the Board of Foundry Services International Ltd.

Mr. **C. Dunger** has been appointed Area Sales Manager for Northern England of Union Carbide Ltd., Alloys Division.

Monsieur **Max Dupont** has left the Centre de Documentation Sidérurgique to become Administrative Director of *La Revue de Métallurgie*.

Mr. **L. R. Evans** has joined the Board of the English Steel Spring Corporation Ltd.

Mr. **J. Glen** (Colvilles Ltd.) has been awarded the degree of Doctor of Science by Glasgow University.

Mr. **C. S. Johnson** has recently been appointed Manager of the Farington Foundries of Leyland Motors Ltd.

Mr. **H. G. Jones** has been elected a Fellow of The Institute of Physics.

Dr. **H. Krainer** has been appointed Head of the Research Department of Fried. Krupp, Essen.

Mr. **W. M. Larke** is President of the Junior Institution of Engineers for 1958–1959.

Mr. **C. E. Lloyd** is to retire on 31st December from the position of Chairman of N. Hingley and Sons, Ltd., which he has held for more than 40 years.

Sir **Arthur Matthews** has retired from the Board of Firth Brown Tools Ltd.

Mr. **J. Mitchell,** C.B.E. (*Past President*) has resigned from the Board of Stewarts and Lloyds Ltd. He joined the Company in 1908 and has been a Director since 1947.

Mr. **W. D. Parry** has left the Consett Iron Co., Ltd., to join the Northern Aluminium Co., Ltd.

Dr. **H. J. Pick** has left Birmingham University to join Joseph Lucas (Electrical) Ltd. as Senior Physical Metallurgist.

Sir **Stanley Rawson** has retired from the Board of Firth Brown Tools Ltd.

Mr. **C. W. Robinson** has been elected a member of the Board of the British-Swedish Chamber of Commerce.

Mr. **N. Stephenson** has left the National Gas Turbine Establishment to join the R. and D. Dept. Laboratories of the Mond Nickel Co., Ltd., Birmingham.

Mr. **W. H. Stratford** has joined the Board of the English Steel Forge and Engineering Corporation Ltd.

Mr. **J. M. Willey** has been elected a Member of Council of the British Welding Research Association.

Mr. **C. H. T. Williams** has been elected Junior Warden of the Company of Cutlers in Hallamshire.

Obituary

Mr. **Paul Henry Cheston** (*elected* 1952), of London, on 9th October, 1958.

Mr. **Aubrey E. Kent** (*elected* 1953), of Vereeniging, Transvaal, South Africa, on 6th September, 1958.

Professor **Archibald Preece,** M.SC., F.I.M. (*elected* 1930), of Newcastle-upon-Tyne, on 13th November, 1958.

Mr. **Arthur Taylor,** A.M.I.MECH.E. (*elected* 1935), formerly of Middlesbrough, in September, 1958.

Mr. **Jakob Teodor Tornblad** (*elected* 1926), of Belfast, on 14th July, 1958.

IRON AND STEEL ENGINEERS GROUP

38th Meeting

The 38th Meeting of the Institute's Iron and Steel Engineers Group will be held at **Caxton Hall, London, S.W.1** (NOT at the Offices of the Institute, as announced earlier) on Thursday, **11th December.** The subject of the meeting will be "Vacuum Processes in the Iron and Steel Industry," and papers will be presented from Belgium, Germany, the U.K., and the U.S.A. It will be an all-day meeting, the morning session starting at 10 a.m. Full details were given in the November *Journal* (pp. 312–313).

AFFILIATED LOCAL SOCIETIES

Swansea Prize Essay Competition

The Swansea and District Metallurgical Society is offering two prizes, of fifteen and five guineas respectively, for essays submitted by young metallurgists or engineers, not over 25 years of age in May, 1959.

The subject is left to the student, but it must be related to research, development, or practice in the

metallurgical industries of South Wales. The essays must not exceed 5000 words, and should be in the hands of the Honorary Secretary by 31st January, 1959. Further details may be obtained from Mr. M. J. A. Thomas, 10 Park View, Port Talbot.

POWDER METALLURGY JOINT GROUP

Symposium on Ceramic–Metal Materials

The next meeting of the Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals will be held at Church House, Great Smith Street, London, S.W.1, on Tuesday and Wednesday, **16th and 17th December,** when there will be a symposium on "The Powder Metallurgy of Ceramic–Metal Materials." The meeting will start at 6.30 p.m. on Tuesday, 16th December, with an introductory paper by Dr. P. Murray, of the Atomic Energy Research Establishment, Harwell. On the following morning at 9.30 a.m., the main part of the Symposium will begin and will continue until about 5 p.m. A series of six papers describing original research work will be presented and discussed.

Visitors will be welcome and tickets will NOT be required.

Papers for this meeting will be published in advance, together with the papers contributed to the first two meetings of the Joint Group and summaries of the discussions on them, in a new publication of the Joint Group which will be on sale by subscription by November. Normally there will be two issues of this publication each year, but for 1958 there will be a double number (1958, Parts 1/2). The annual subscription price, post free, to non-members of the two Institutes is 25*s*., and to members of either The Iron and Steel Institute or The Institute of Metals it is 10*s*. per annum.

Orders for this publication should be addressed to The Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London, S.W.1.

CONTRIBUTORS TO THE JOURNAL

T. R. Allmand, L.I.M.—Steelmaking Division, British Iron and Steel Research Association.

Mr. Allmand received his metallurgical education at Battersea Polytechnic as a full-time student. On completing his studies in 1951 he joined the research staff of the David Brown Foundries Co., Ltd., Penistone, and took charge of their creep laboratory. In 1953 he left to join the Metallurgy (General) Division of B.I.S.R.A. at Sheffield, where he was connected with work on fatigue and non-metallic inclusions. Mr. Allmand was transferred to the Steelmaking Division in 1956.

W. C. Fletcher. B.SC.(HONS.), A.I.M.—General Manager, Rhodesian Iron and Steel Co., Ltd.

William Corcoran Fletcher was born in 1920 and educated at Quarry Bank High School and Liverpool University, where he obtained a B.Sc. Honours degree. He joined Stewarts and Lloyds Ltd. in 1942 to work in the Department of Research and Technical Development. In 1945 he became Personal Assistant to Dr. Dickie on technical development and works trials, and five years later was put in charge of the Technical Development Section. Mr. Fletcher became Chief Works Metallurgist in 1955, a post he held until being appointed General Manager of The Rhodesian Iron and Steel Co., Ltd., on 1st January, 1958.

T. R. Allmand

E. J. Wynne

E. J. Wynne, B.SC. (HONS.)—Research Student, King's College, Newcastle-upon-Tyne.

Mr. Wynne was born in 1935 and educated at Wallsend Grammar School and King's College, Durham University. He obtained an honours degree in metallurgy in 1957, and is at present working with Dr. R. F. Tylecote on some aspects of pressure welding.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Forge Modernization

On 16th and 17th September, a conference arranged by B.I.S.R.A. on the subject of "Modernization of Forges" was held at Ashorne Hill, near Leamington Spa, under the Chairmanship of Mr. F. J. Somers (Walter Somers Ltd.). The attendance was over a hundred from more than 40 member firms of the Association.

Three papers were presented for discussion. The first, "*Building a new forge*," was given by Mr. A. C. Lowe (Thos. Firth and John Brown Ltd.), who spoke about the rebuilding of the 1750-ton press shop at their Atlas Works. He described the factors that had to be taken into account when the question of rebuilding was under consideration and the way in which their new plant was fitted in with the existing facilities, and gave their present thoughts regarding the layout and operation after some months' working experience.

The second paper, "*Features that make for a well-designed modern forge*," was given by Mr. E. Homer Kendall (Kendall Contracting Inc., Alliance, Ohio). He stressed the need to allocate separate space to (i) the heating process, (ii) the forging process proper, and (iii) the laying down of completed jobs and any necessary heat-treatment, so as to ensure the greatest flexibility in operation and unimpeded flow of work. He then went on to discuss the factors which determine the type of equipment that should be installed in each. His paper contained many references to forge layouts with which he was acquainted that illustrated the points he was making.

The last paper, given by Mr. J. Banbury (B.I.S.R.A. Operational Research Department), was entitled "*A method for comparing alternative ways of forging.*" Mr. Banbury, referring to work carried out by his department, showed how the method had been used by a company to compare an existing forge with a proposed new forge for the purpose of deciding whether to re-equip. He also described the way in which the same technique could be used for comparing different forges so that cost- and time-saving factors could be pinpointed.

The discussion on these papers was extremely lively, indicating the wide interest in the forging industry today in modernization. Latest developments excited particular interest and were further emphasized by the showing of a film of the B.I.S.R.A. experimental forge, in which the development of automatic forging is at an advanced stage. A further film by the English Steel Corporation Ltd. bore witness to the wide range of processes and equipment required in forging.

After the formal conference session, the members visited the forges of Walter Somers Ltd., Halesowen, by

courtesy of the company, and there saw in operation a new light forge of advanced design.

Conference on Iron and Steelworks Buildings

The Plant Engineering and Energy Division is arranging a conference on "Iron and Steelworks Buildings," which will be held at Ashorne Hill from 13th to 15th January, 1959. In addition to papers covering U.K. steelworks structures, papers will be presented by French and German designers. Civil and structural engineering aspects which influence capital and maintenance costs and facilities for improving output will be considered. The proceedings will close with a paper on the architectural aspects of steelworks buildings by a prominent British architect, who will also summarize the proceedings of the Conference.

Further details may be obtained from the Technical Secretary, Plant Engineering and Energy Division, B.I.S.R.A., 140 Battersea Park Road, London, S.W.11.

EDUCATION

Plasticity of Production Processes

The Department of Mechanical Engineering of the Imperial College of Science and Technology is holding an intensive three-week course from 20th April to 8th May, 1959, during which the most important technological theories and researches underlying the major metal-working and machining processes will be considered. The course is intended for graduates in engineering, physics, or mathematics who are concerned with production processes and either require a refresher course in the principles of metalworking or have little or no knowledge of the subject. Many of the lectures will be given by experts from industry.

Further details and application forms may be obtained from the Registrar, Imperial College, London, S.W.7.

Aircraft Materials

A Department of Aircraft Materials has now been established at The College of Aeronautics, Cranfield, to offer a course in this subject for postgraduate College Diploma students. The course will cover engineering techniques in applications of both metallic and non-metallic materials, as well as the basic relevant sciences, especially physical metallurgy and solid-state physics. Students for this new specialization will co-operate in the Department's research projects, which currently are mainly in the fields of creep and fatigue.

Corrosion Essay Competition

The Corrosion Group of the Society of Chemical Industry is once again offering a prize of twenty-five guineas for an essay on any aspect of the corrosion of metals and its prevention. This competition, which was initiated in 1955, is designed to encourage those in the early stages of their career to take an interest in corrosion science and to express their ideas in writing.

Essays are invited from persons aged not more than 27 on the closing date (31st March, 1959). A length of about 4000 words is suggested. The judges will base their decision on the evidence shown of the candidate's critical faculty and originality of thought. Original research may be incorporated, but this is not essential.

Full details may be obtained from the Corrosion Group, Society of Chemical Industry, 14 Belgrave Square, London, S.W.1.

NEWS OF SCIENCE AND INDUSTRY

Coal Science Lecture

The British Coal Utilisation Research Association's Seventh Coal Science Lecture was delivered at the Institution of Civil Engineers on 15th October by Sir Charles Goodeve, O.B.E., F.R.S., Director of the British Iron and Steel Research Association. He took as his subject "Carbon: the key to metallurgy."

Sir Charles began by referring to the remarkable role played by carbon in the history of extraction metallurgy; the commercial production of most of the important chemical elements depends on the use of carbon to reduce an oxide or some other compounds containing oxygen in combination. Carbon had two further important roles—it was used as a ceramic in the manufacture of uranium, and it imparted greater strength to metals, notably to iron in the production of steel.

After discussing the reason for carbon's importance in these operations, Sir Charles went on to discuss the chemical engineering and kinetic aspects of reactions in which carbon took part. He did not think that carbon's unique position was likely to be seriously challenged in the foreseeable future.

A dinner was held after the Lecture at the Savoy Hotel, at which Sir Charles was presented with the Coal Science Medal by Dr. W. Idris Jones, C.B.E., President of B.C.U.R.A.

The Factories Acts

Modern industry demands of management a good working knowledge of the Factories Acts and related legislation. The United Steel Companies Ltd., recognizing this need, issued in 1945 a summary of the Acts, written in the language of the layman and bringing together in a handy reference booklet the main provisions of the Acts as applying to the iron and steel industry. This summary has now been revised and brought up to date by the Company's Safety Consultant, Mr. N. H. Jones, an ex-Deputy Chief Inspector, who served with H.M. Factories Inspectorate for 42 years. Copies may be obtained, free of charge, by interested persons on application to the Welfare Office, The United Steel Companies Ltd., 17 Westbourne Road, Sheffield 10.

B.C.A.C. Bulletin

The British Conference on Automatic and Computation, of which The Iron and Steel Institute is a member, has recently issued the first number of *B.C.A.C. Bulletin*, a bi-monthly publication. It is proposed to give details of meetings and other matters of interest in the field covered by the Conference. The cost to individual members of member organizations will be 1*s.* per copy (6*s.* per annum), and 2*s.* per copy (12*s.* per annum) to others. Orders should be sent to B.C.A.C. Bulletin, c/o The Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

Fuel Efficiency Lecture

During the Fuel Efficiency Exhibition at Olympia, Mr. R. P. Towndrow, of Colvilles Ltd., delivered a lecture on "Fuel Efficiency in the Iron and Steel Industry" on 1st October. The lecture, which was given on behalf of the British Iron and Steel Federation, was well attended; Mr. R. L. Willott, D.S.O., O.B.E., Chief Engineer of John Summers and Sons, Ltd., was in the chair.

The Federation's stand at the Exhibition illustrated some of the technical developments, described by Mr. Towndrow, that had made possible the infinitely greater efficiency in the industry, which now makes 2½ times as much steel as it did in 1923, but uses only the same amount of fuel.

Nimonic 105

The latest addition to the Nimonic series has recently been announced by Henry Wiggin and Co., Ltd. Nimonic 105 is a development of Nimonic 100; it has greater

resistance to creep at very high operating temperatures, the minimum life to rupture at 7 tons/in² and 940° C being 50 h.

Sinter Cooler for Workington

The Workington Iron and Steel Co., Ltd., has ordered a Lurgi-Frodingham circular sinter cooler (94 m² effective area) of the type developed for the Apex and Seraphim plants at Appleby-Frodingham, from Lurgi Gesellschaft für Chemie und Hüttenwesen M.B.H. of Frankfurt-am-Main.

Industrial Publications Received

Brochures Nos. 90 (Proportioning Air Burner), 100 (Self-clean Metering Oil Valve), and 110 (Micro-cam Oil Valve) describe some items in the range of Hauck equipment now available from Stordy Engineering Ltd.

"Wiggin Nickel Alloys *v.* Caustic Alkalies" is the title of a publication issued by Henry Wiggin and Co., Ltd., describing the properties of the high-nickel alloys used in the construction of plant handling caustic soda.

General Refractories Ltd. have recently published a leaflet on Chelford Silica Sands (publication no. 90).

The range of reverberatory melting furnaces produced by the company is described in a booklet from Sklenar Furnaces Ltd., Cardiff.

The latest publication from Hilger and Watts Ltd. deals with the Hilger Wavelength Spectrometer (Models D186 and D.187).

Holmes-Connersville Exhausters and Boosters Type XAS are the subject of Publication No. 75 from W. C. Holmes and Co., Ltd.

A brochure from Leybold Vacuum Sales Ltd. describes the range of vacuum furnaces supplied by Degussa Wolfgang Industrieofenbau.

A new range of fibreglass air filter panels are featured in a leaflet from Vokes Ltd., Guildford.

Brochure No. 582 from The Visco Engineering Co., Ltd., describes the Bermax automatic dust collector, in which a mineral filtration medium is used in place of textile filter tubes, making it especially suitable for high-temperature conditions.

Allcase controlled-atmosphere batch furnaces are described in Bulletin No. 65 from British Furnaces Ltd.

The Burstlein–Longwy process for producing metallurgical coke from poorer coking coals is the subject of a brochure from the Woodall-Duckham Construction Co., Ltd.

Whittaker, Hall and Co. (1929) Ltd., have recently issued a catalogue on Hydrovane oil-flooded rotary compressors.

Changes of Address

The Midland Coke Research Station has moved to the British Coke Research Association's laboratories, Chesterfield.

Refractory Mouldings and Castings Ltd. have moved to larger premises in Market Place, Kegworth, Derbyshire.

The telephone number of Wild-Barfield Electric Furnaces Ltd. is now Watford 26091.

Acheson Industries (Europe) Ltd. have moved from Pall Mall to 1 Finsbury Square, London, E.C.2 (telephone MONarch 5811).

The London Office of the Lancashire Steel Manufacturing Co., Ltd., is now 17 Northumberland Avenue, London, W.C.2.

Protolite Ltd. have moved their main office from London to Rainham, Essex (telephone Rainham 3322). A Southern Region Area Office will be maintained at Central House, Upper Woburn Place, London, W.C.1.

Corrigenda

Mr. P. E. Peck (The British Thompson-Houston Co., Ltd.) has asked us to substitute the following for his contribution to the discussion on electrical maintenance in iron and steelworks (*J.I.S.I.*, 1958, Sept., vol. 191, pp. 75–76):

> Regarding air filters, a viscous filter is often preferred as being a good all-round job, not too difficult to maintain, not too expensive, and not too elaborate. Others prefer a recirculating system with electrostatic filtration of the make-up air, maintaining that the oil from viscous filters is carried into the electrical machinery, with consequent excessive dust collection.
>
> Has anyone had experience of the moving-curtain type of viscous filter comprising an intermeshed net of short wiry parts which can be continuously or intermittently in motion? The wires open out as the curtain passes round its end rollers, thus rendering the removal of dirt by oil sprays much more effective.
>
> Objection has been raised to the use of plug contacts for replaceable apparatus. We are meeting this in our control gear by having unit contactors, removable from their panels or frameworks by disconnecting interlocking and coil leads and the main connections. They can then be serviced or replaced.
>
> For multimotor control units, however, we are using pressure-finger and butt-type contacts for main and control connections respectively and finding them very satisfactory. Oil circuit breakers are largely dependent on such contacts and on the whole they give very good service.

The following translating errors have been pointed out in the paper by Speith and Bungeroth on "Continuous Casting of Steel in Western Germany" (*J.I.S.I.*, 1958, Oct., vol. 190, pp. 158–161):

p. 160 Section on "Casting Ladles," line 8: "Tilting *ladles*," not furnaces.

p. 160 Section on "Intermediate Receiver," 5th para., 2nd sentence should read "Individual control for each mould, which is *absolutely necessary* with more than four strands, can be . . ."

p. 161 Section on "Mould Design," 1st para., last sentence, should read "Separate types may be distinguished, such as those of *seamless tubes* and multisectional moulds consisting of plates."

p. 161 Section on "Special Design Characteristics," 2nd para.: ". . . the weight of the ingot derived from the *metric* weight of the casting . . ."

p. 161 Section on "Special Design Characteristics," last three paragraphs should read:

> "For the light sections, the use of one or two pairs of pinch rolls is recommended. They should be arranged as overhung rolls to hold the ingot with continuous and uniform pressure. Both rolls are moveable symmetrically to the axis of the bar.
>
> With heavy sections these cannot be used; two, three, or more pairs of rolls, supported at both ends, must be provided. These have fixed rolls on one side and moving pressure rolls on the other.
>
> For single and two-strand installations, . . . the plant can be divided vertically into a "cold" and a "hot" side. In other cases the strands must be arranged in a stack in the centre of the casting unit."

DIARY

1st Dec.—CLEVELAND INSTITUTION OF ENGINEERS—"Production and Use of Basic Slag," by J. H. Thompson—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

2nd Dec.—EAST MIDLANDS METALLURGICAL SOCIETY—"Refining Nickel," by H. C. Castell—Electricity Showrooms, Smithy Row, Nottingham, 7.30 p.m.

2nd Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—"Steelmaking in Small Furnaces," by T. A. Cosh—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

3rd Dec.—MANCHESTER METALLURGICAL SOCIETY—"Metallurgical Control in Mass Production," by J. E. James—Central Library, Manchester, 6.30 p.m.

4th Dec.—BRITISH NUCLEAR ENERGY CONFERENCE—"Thermonuclear Processes," by D. W. Fry—Institution of Electrical Engineers, Savoy Place, London, W.C.2, 5.30 p.m.

4th Dec.—LEEDS METALLURGICAL SOCIETY—"Thermodynamics in Metallurgy," by Dr. J. Lumsden—Chemistry Wing, University of Leeds, 7.15 p.m.

5th Dec.—BRITISH NUCLEAR ENERGY CONFERENCE—"An Experimental Investigation into the Stress Distribution in a Band-reinforced Pressure Vessel," by K. G. Mantle, N. Marshall, and P. J. Palmer—Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1, 6 p.m.

5th Dec.—SHEFFIELD METALLURGICAL ASSOCIATION—Annual Dinner-Dance—Royal Victoria Hotel, Sheffield.

6th Dec.—Liverpool Metallurgical Society—First Annual Dinner.

8th Dec.—Lincolnshire Iron and Steel Institute—"Engineering Aspects of a Modern Open-hearth Melting Shop," by J. A. Kilby—North Lindsey Technical College, Scunthorpe, 7.30 p.m.

9th Dec.—British Nuclear Energy Conference—"The Use of Radioactive Isotopes for the Investigation of Sewage Treatment Plant," by S. G. Burgess and A. F. Green—Institution of Civil Engineers, Great George Street, London, S.W.1, 5.30 p.m.

9th Dec.—Ebbw Vale Metallurgical Society—"The Manufacture of Stainless Steel," by G. Williams—R.T.B. Lecture Rooms, 7.15 p.m.

9th Dec.—The Iron and Steel Institute—*11th Hatfield Memorial Lecture*: "The Mechanical Properties of the Ferrite Crystal," by Dr. N. P. Allen, F.R.S.—Institution of Naval Architects, 10 Upper Belgrave Street, London, S.W.1, 6 p.m.

9th Dec.—Newport and District Metallurgical Society—"Oxygen in Steelmaking," by D. J. O. Brandt—Whitehead Institute, Newport, 7 p.m.

9th Dec.—Sheffield Metallurgical Association—"On Getting to Know Ceramic Technology," by Dr. N. F. A. Astbury—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

10th Dec.—North Wales Metallurgical Society—"Metallurgy, Commerce, and Zinc Surfaces," by Dr. W. H. F. Tickle—Flintshire Technical College, Connah's Quay, 7 p.m.

10th Dec.—The Iron and Steel Institute—Autumn General Meeting—Caxton Hall, Caxton Street, S.W.1, 10.30 a.m.

11th Dec.—The Iron and Steel Institute (Iron and Steel Engineers Group)—Meeting on Vacuum Processes—Caxton Hall, Caxton Street, London, S.W.1.

11th Dec.—Liverpool Metallurgical Society—"The Metallurgical Applications of High-resolution Electron Microscopy," by Dr. J. Nutting—Department of Metallurgy, University of Liverpool, 7 p.m.

11th Dec.—North-East Metallurgical Society—"Bearing Metals from the User's Viewpoint," by R. J. Brown—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

11th Dec.—Staffordshire Iron and Steel Institute—Film Evening—Station Hotel, Dudley, 7.30 p.m.

13th Dec.—Swansea and District Metallurgical Society—"Modern Developments in Furnace Design," by Dr. W. P. Bacon—Central Library, Swansea, 6.30 p.m.

15th Dec.—Sheffield Society of Engineers and Metallurgists—"Continuous Casting at Barrow," by I. M. D. Halliday—Sheffield University, 7.30 p.m.

16th Dec.—Sheffield Metallurgical Association and Institution of Metallurgists—"Imperfections in Metals," by Professor N. F. Mott, F.R.S.—Engineering Lecture Theatre, St. George's Square, Sheffield, 7 p.m.

16th–17th Dec.—Powder Metallurgy Joint Group—Symposium on the Powder Metallurgy of Ceramic–Metal Materials—Church House, Great Smith Street, London, S.W.1.

19th Dec.—Society of Chemical Industry (Corrosion Group)—"Modern Views of Electrochemical Processes," by Dr. E. C. Potter and Dr. T. P. Hoar—14 Belgrave Square, London, S.W.1, 2.30 p.m.

26th–31st Dec.—American Association for the Advancement of Science—Annual Meeting—Washington, D.C., U.S.A.

5th Jan.—Cleveland Institution of Engineers—"Blast-furnace Techniques," by Dr. T. P. Colclough—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

6th Jan.—Institution of Engineering Inspection—"An Introduction to Engineering Metallurgy," by C. C. Griffin—Coventry Technical College, 7.30 p.m.

6th Jan.—Sheffield Metallurgical Association (Methods of Analysis Group)—Annual General Meeting—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

6th Jan.—Society of Chemical Industry (Corrosion Group and Birmingham and Midland Section)—"Alloys for High-temperature Service," by D. A. Oliver, C.B.E.—Birmingham and Midland Institute, Paradise Street, Birmingham, 6.30 p.m.

7th Jan.—Newport and District Metallurgical Society—"The Historical Development of the Rolling Mill," by E. C. Larke—Whitehead Institute, Newport, 7 p.m.

8th–9th Jan.—British Society of Rheology—Conference on Fracture, Fatigue, and Failure—University of Leeds.

8th Jan.—Liverpool Metallurgical Society (Joint Meeting with the University of Liverpool Metallurgical Society)—Student Prize Competition—Department of Metallurgy, University of Liverpool, 7 p.m.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 316 of the November, 1958, issue of the *Journal*:

817. Koch, W., *et al.*: "Microanalytical Investigations in Ferrous Metallurgical Research." III—Handling Microgram Quantities in Metallurgical Investigations. *Arch. Eisenhüttenwesen*, 1957, Dec., pp. 785–794. (£6)

837. Boghen, J., and J. Herenguel: "Rapid Tests for the Evaluation of the Hot Behaviour of Metals" (with especial reference to Aluminium). *Rev. Mét.*, 1957, Sept., pp. 733–736. (£2 10*s.* 0*d.*)

876. Speith, K.-G., *et al.*: "Desulphurization in the Basic Converter." *Stahl u. Eisen*, 1958, Feb. 6th, pp. 152–156. (£4)

903. Pottgeiser, H.: "Decarburising Reaction in the Basic Bessemer Process during De-phosphorisation." *Stahl u. Eisen*, 1958, March 6th, pp. 291–298. (£4 5*s.* 0*d.*)

928. Shubalev, M. V., and S. G. Nekrasov: "Calculation of Rolling Spread." *Stal'*, 1958, Jan., pp. 57–60. (£2)

964. Mankher, L.: "Defects in Steel Wire." *Kohászati Lapok*, 1953, Nov., pp. 225–239. (£10)

1000, 1003, 1005–1007. *Papers presented at the International Transport Conference, June 1958, Liège.*

1000. Fortebre, R.: "The Main Element of the Cost of Internal Transport: Charging." (£5)

1003. Willem, P.: "Steelworks Railway Maintenance: New Methods and Mechanisation." (£8 5*s.* 0*d.*)

1005. Müller, A.: "Modern Methods and Procedures for the Maintenance of Works Railway Track." (£6 10*s.* 0*d.*)

1006. Gesell, W.: "Transport of Lime and Scrap in an Open-hearth Furnace Steelworks." (£6)

1007. Lafon, A. F. de, and G. Gabrielle: "Handling of Lime and Scrap in Steelworks." (£4)

1029. Koch, W., and H. Sundermann: "Electrochemical Basis of the Isolation of Structural Components in Steels." *Arch. Eisenhüttenwesen*, 1957, Sept., pp. 557–566. (£7 10*s.* 0*d.*)

1041. Chekmarev, A. P., and G. I. Gulyaev: "Roll Design for Reducing and Sizing Mills." *Stal'*—Rolling and Tube Manufacture Supplement, 1958, pp. 276–294. (£5 10*s.* 0*d.*)

1045. Koerfer, E., *et al.*: "The Effect of Heat Treatment on the Machinability by Turning and Drilling of Plain Carbon Steel containing about 0·45% C with special regard to the Steel Melting Method used." *Stahl u. Eisen*, 1956, Feb. 9th, pp. 125–133. (£5)

1049. Lueg, W., and P. Funke jnr.: "The Calculation of the Effect of the Rolling Speed on the Rolling Effort and the Strip Thickness in Cold Rolling." *Stahl u. Eisen*, 1957, Oct. 3rd, pp. 1356–1362. (£4 15*s.* 0*d.*)

1060. Collette, G.: "Calorimetric Investigations on the Kinetics of the Isothermal Breakdown of Austenite in a 12% Manganese Steel." *Arch. Eisenhüttenwesen*, 1957, Apr., pp. 229–235. (£5)

1061. Andreev, V. F.: "On the Economic Efficiency of using Oxygen in the Iron and Steel Industry." *Stal'*, 1958, June, pp. 561–568. (£6 10*s.* 0*d.*)

1062. Leroy, P., and G. Cohen de Lara: "Hydrodynamic and Practical Study of the Movement of the Bath in the Bottom-blown Converter." Chapter II—'Study of Ejections from a Bottom-blown Circular Converter, starting from a Study of Mass Oscillations of the Bath'; Chapter III—'Study on Small Scale Models of Bath Movements and Ejections with an Oval Converter.' *Rev. Mét.*, 1958, Feb., pp. 186–200. (£7)

1063. Brockhaus, J. G., *et al.*: "Study of the Effect of Different Working Conditions of a 3-stand Cold-rolling Tandem Mill Train on the Mechanical Properties of Strip Steel." *Stahl u. Eisen*, 1958, July 10th, pp. 955–960. (£4)

1064. Glaesener, E.: "New Method of Vibrating Converter Bottoms." *Rev. Univ. Mines*, 1958, Aug., pp. 261–269. (Also published in Stahl u. Eisen and Rev. Tech. Luxembourg) (£5)

1065. Kölbel, H.: "Possible Uses of Blast Furnace Gas for the Synthetic Production of Hydrocarbons." *Stahl u. Eisen*, 1958, Aug. 21st, pp. 1165–1169. (£3 10*s.* 0*d.*)

1066. Briffaux, J.: "Discussion of Methods leading to Improvements in High-voltage Power Lines." (Abridged: translation covers structural aspects of article, omitting electrical data) *Bull. Soc. Belge Électriciens*, 1957, (2), pp. 85–105. (£5)

1067. Pusch, R., and H. J. Schüller: "A Fringe-like Eutectoid in the Transformation Structure of Heat-resistant Steels having a Low or Medium Alloy Content." *Arch. Eisenhüttenwesen*, 1958, Jan., pp. 65–72. (£5 5*s.* 0*d.*)

1069. Schleicher, W., and K. Bolec: "A New Oil Firing System for Open-Hearth Furnaces." *Stahl u. Eisen*, 1958, Aug. 7th, pp. 1108–1109. (£2)

1074. Mednikov, Yu. A., and G. K. Strizhak: "An Electrostatic Method for Painting and Oiling Tubes." *Metallurg*, 1958, May, pp. 30–34. (£2 10*s.* 0*d.*)

1079. Schenck, H., *et al.*: "Investigations into the Isolation of Grain Boundary Materials and Inclusions in Steels by the Thin Section Process." *Arch. Eisenhüttenwesen*, 1958, Aug., pp. 479–484. (£5)

1084. Jacquet, P. A.: "Rapid Method of Preparation of Surfaces for Metallographical Examination by Local Electrolytic Polishing." Note Technique No. 40, 1957. Office National d'Études et de Recherches Aéronautiques (ONERA) (£4 10*s.* 0*d.*)

1090. Vinograd, M. I.: "Optimum Chemical Composition of Steel 1Kh18N9T." *Metallurg*, 1957, May, pp. 13–16. (£2 15*s.* 0*d.*)

1100. Kidin, I. N.: "Influence of Induction Heating on the Austenitic Grain of Carbon Steels." (Summary) *Metallov. Obra. Met.*, 1956, Jan., pp. 40–41. (£1)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

CONTENTS

Note.—The letters *a*, *b*, and c refer to the three columns of the page concerned.

	PAGE
Ores—Mining and Treatment	437*a*
Fuel—Preparation, Properties, and Uses	438*a*
Refractory Materials	438*b*
Iron and Steel, General	438*b*
Blast-Furnace Practice and Production of Pig Iron	438*c*
Properties, Treatment, and Use of Slags	439*b*
Direct Processes	439*c*
Production of Steel	439*c*
Production of Ferro-Alloys	442*a*
Foundry Practice	442*a*
Vacuum Metallurgy	445*a*
Reheating Furnaces and Soaking Pits	445*a*
Heat-Treatment and Heat-Treatment Furnaces	445*a*
Forging, Stamping, Drawing and Pressing	446*a*
Rolling Mill Practice	446*c*
Machinery and Services for Iron and Steel Plant	447*a*
Lubrication	447*a*
Welding and Flame-Cutting	447*a*
Machining and Machinability	448*b*
Cleaning and Pickling	448*c*
Protective Coatings	449*a*
Powder Metallurgy	449*b*
Ferrites, Cermets, and Carbides	449*c*
Properties and Tests	449*c*
Metallography	450*c*
Corrosion	452*b*
Analysis	453*b*
Industrial Uses and Applications	454*a*
Historical	454*a*
Economics and Statistics	454*b*
Miscellaneous	454*c*
Book Notices	454*b*
New Publications	455*b*

*Abstracts, the reference to which is marked with an asterisk are to be made available as translations.

ORES-MINING AND TREATMENT

Iron Baron Comes to Life. (*B.H.P. Rev.*, 1958, **35**, Apr., 24–26). The reopening of an iron ore quarry (in N.S.W.) is briefly described.

New Zealand Iron Sands. (*Chem. Eng. Min. Rev.*, 1958, **50**, May 15, 39–41). A brief review of the types found and of attempts to establish a steel industry.

Speeding Ore Handling at Hartlepool. (*Iron Coal Trades Rev.*, 1958, 177, Aug. 15, 363–364). A brief account of the use of crawler tractors in iron ore unloading operations.

Dragline Excavators. J. M. Caw. (*Mine Quarry Eng.*, 1958, Sept., 398–406). Various types are shown, some working on ironstone.

Dry Magnetic Separation of Finely Ground Magnetite. U. Runolinna. (*Trans. International Mineral Dressing Congr.*, 1957, *Stockholm*, 1958, 255–284). Laboratory and plant scale experiments are described and fineness of grinding, magnetic field intensity, drum speed and the effect of conditioning with fatty acids are discussed.

Flotation of Haematite Ores with Tall Oil Emulsions. P. G. Kihlstedt. (*Trans. International Mineral Dressing Congr.* 1957, *Stockholm*, 1958, 559–576). Selective flotation of haematite and apatite is described.

Magnetic Separation. Basic Principles and Their Practical Application. P. M. Sheahan. (*Proc. Australasian I.M.M.*, 1958, June, 135–159).

The Dissolution of Sulphide Ores in Acid Chlorine Solutions; a Study of the More Common Sulphide Minerals. K. J. Jackson and J. D. H. Strickland. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 373–379). The rates of reaction and products of the reaction between acid chlorine water and a number of sulphide minerals were studied, including the iron ores FeS_2, FeS and FeAsS. All these materials form sulphate. Some practical applications in the treatment of the ores are discussed.

A Kinetic Study of the Oxidation of Pyrites in Aqueous Suspension. D. R. McKay and J. Halpern. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 301–309). The kinetic study was carried out with molecular oxygen at 100–130° C. The contribution of several possible reactions were assessed separately, a detailed study of the oxidation of ferrous sulphate being made. The effects of stirring, surface area and pulp density, O_2 pressure, temperature and other factors on the oxidation of pyrites were investigated. The results are discussed.

Reductive Leaching of Ores, Especially Manganese Ores. G. Björling. (*Trans. International Mineral Dressing Congr.*, 1957, *Stockholm*, 1958, 705–709).

Magnetic Roasting of Haematite. S. Eketorp. (*Trans. International Mineral Dressing Congr.* 1957, *Stockholm*, 1958, 285–303). Two types of Swedish ore were roasted. Heat economy is considered and a new type of recuperative rotary furnace is described in which the feed is heated by the outgoing roasted ore which leaves with a temperature of no more than 100–150° C.

The Influence of Fluidized Roasting on Hydrometallurgical Processes. J. D. Grothe and B. H. McLeod. (*Trans. International Mineral Dressing Congr.* 1957, *Stockholm*, 1958, 675–682). Cobalt concentration from chalcocite-carrolite and pyrites are included.

Taconite Pellets—Problems of Carloading, Stockpiling and Loading Vessels at Eric Mining Company. L. O. Millard. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 99–109). The Erie Mining Co's pelletizing plant at Hoyt Lakes is designed for an annual production of 7½ million gross tons. From the plant, the pellets are transported to the company's port at Taconite Harbor. The author describes the methods adopted for overcoming the many problems in handling and transporting pellets.—G. F.

Modern Ore Sintering Plant in Operation at Cleveland Works of J & L Steel Corp. (*Ind. Heat.*, 1958, **25**, July, 1388, 1392). A plant with a daily capacity of 2500 t is briefly described.

Developments in Sintering Efficiency. W. Davies and D. W. Mitchell. (*Trans. International Mineral Dressing Cong.* 1957, *Stockholm*, 1958, 305–364). The demand for sinter in the U.K. is reviewed. A theory is outlined in which the propagation of a sintering heat wave is considered and observations are made on the mechanism of combustion of coke. Effects of fuel and humidity are discussed and control by pre-heated air is postulated. Air demand and flow are related to permeability and the principles established are applied to plant design and operation.

Distribution of Sinter Mix by the Swinging-Spout Method. W. J. Eisman, D. R. Dalton, and J. T. O'Connor. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 150–162). The authors present the results of an investigation of the distribution of particle sizes and carbon in the bed of sinter mix, deposited by the swinging-spout method in the Gary Works sinter plants of United States Steel Corp. Studies of air flow through the bed and the quality of the sinter are included. The swinging-spout is shown in an unfavourable light as a distributor of the mix.—G. F.

How Can Theory Help Us to Make More Sinter? E. W. Voice and R. Wild. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 121–146). Details are given of a B.I.S.R.A. investigation into the fundamentals of the sintering process, the main feature being an effort to simplify the process and separate the phenomena which can occur during sintering so that each could be studied individually. The experimental procedure is outlined, and the results obtained and their relevance to plant problems are discussed.—G. F.

Agglomeration of Haematite Concentrates Using Updraught Grate-Firing Techniques T. E. Ban. (*Trans. International Mineral Dressing Congr.* 1957, *Stockholm*, 1958, 365–392). A laboratory study on pelletizing a flotation concentrate is reported. Large scale plant was constructed and is described. Methods for continuous operation are evolved from batch tests. Tests on the strength of green pellets are described and combustion and heat transfer are considered.

Updraft Method for Pelletizing Specular Hematite Flotation Concentrates. D. C. Violetta. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 110–119). The author describes the development of an updraft-fired process for pelletizing specular hematite flotation concentrates. He deals first with laboratory and pilot-plant experiments, which led to the design of the 2000 t/day Eagle Mills pelletizing plant. The operation of this plant is described.—G. F.

Properties of Self-fluxing Sinter. N. L. Gol'dshtein and N. S. Khromchenko. (*Stal'*, 1958, (7), 586–593). Free and combined iron oxides are discussed. The amount

depends on the gangue materials rather than on the amount of FeO if this is not over 22–25%. The combined oxygen in ferric oxides does not exceed 10–12% irrespective of basicity. Reducibility can only be evaluated by kinetic studies and is determined mainly by the state of the free iron oxides, their absorptive activity and their capacity for reaction with gases.

Iron-Coke Process. H. Barking and C. Eymann. (*J. Met.*, 1958, **10**, Apr., 274–276). A description is given of the Walsum process for producing a metallurgical coke from high-volatile coals which cannot be carbonized alone. The process involves admixing iron ore. The properties of the resulting iron-coke are discussed.—G. F.

FUEL—PREPARATION, PROPERTIES AND USES

An Annotated Bibliography on Coal. P. O. Yingst. (*Colorado School of Mines, Quarterly*, 1958, **53**, July, pp. 102). A section on coking is included.

New Methods of Preparing Coking Coals. N. S. Grjaznov. (*Paliva*, 1958, **38**, (7), 238–243). [In Czech]. An improved utilization of inferior coking coals is possible by the use of selective milling or fine milling together with selective milling. The strength and coking rates of the coke is affected advantageously by preheating to 100–200° C prior to charging into the coke oven. Experimental data supporting the conclusions are given.

Some Aspects of Illawarra Coals for the Production of Blast Furnace Coke. R. W. Gadsden. (*Proc. Australasian I.M.M.*, 1958, June, 187–206). Blast furnace trials are included.

The Crushing of Coking Coals. IV. V. Charvát and B. Kedroň. (*Paliva*, 1958, **38**, (7), 234–237). [In Czech]. Laboratory and full scale tests on coals obtained from several Ostrava pits showed the desirability of grinding to a uniform small particle size of about 0·15 in. for best coking results. Suggestions for improving the performance and design of the crushing mills, based upon the experiments, are detailed.—P. F.

Better Utilization of Coking Coals. A. H. Brisse. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 239–247). The author reviews certain items of interest in the fields of coke and coal technology, and broadly indicates the close economic inter-relationship that exists between all process steps concerned with coal and coke production and utilization.

Rebuilding a Coke-Ovens Battery. A. Cornish. (*B.H.P. Rev.*, 1958, **35**, Apr., 21–23). An account of a "Wilputte" installation at Newcastle (N.S.W.).

Maintaining and Operating a Coke Plant During Curtailment of Operations. J. H. Kunkle. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 76–80). The author describes the maintenance and operating procedures and methods adopted during periods of curtailment at the Cleveland, Youngstown, Central, Southern, Chicago, and Warren coking plants of the Republic Steel Corp. A number of particular problems are considered.

Shutdown, Maintenance and Starting Up of Clairton Coke and Coal-Chemical Works. P. Palumbo. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 80–85). The author describes the preparations made for curtailing operations at the Clairton coking plants of United States Steel Corp., and outlines the shutdown operation. The maintenance of the plant during shutdown is discussed and finally details are given of the procedure for re-starting operation.—G. F.

Standby Operations During Strikes at Inland Steel Company, Indiana Harbor Works. C. L. Corban. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 85–88). Details are given of standby operations during curtailment periods at Inland Steel Co.'s coking plants, and of the method of restarting production.—G. F.

The Recovery of Heat from Incandescent Coke in Gas and Coke Works. W. Herschc. (*Sulzer Tech. Rev.*, 1957, **39**, (4), 15–29). An account of the Sulzer dry coke cooling system and its combination with steam, hot-air or gas turbines is given.

High-Temperature Testing of Blast Furnace Coke. M. O. Holowaty and C. M. Squarcy. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 249–266). The authors describe the development of a high-temperature compression test for coke, giving details of the apparatus and the method of testing. Results on different cokes are given and compared with their performance in the blast furnace, showing that the test simulates the conditions encountered by the burden in the high-temperature zone of the blast furnace and permits satisfactory prediction of relative performance characteristics.—G. F.

Recovery of Sulphur from Coke Oven Gas. (*Engineering*, 1958, **186**, Aug. 15, 223). A note on the process at Appleby-Frodingham.

REFRACTORY MATERIALS

New Basic Refractories Plant of Harbison-Walker at Hammond, Ind. (*Ind. Heat.*, 1958, **25**, July, 1425–1426, 1428, 1430, 1432, 1434, 1436, 1440, 1442, 1443).

Contribution to the Study of Thermal Shock. H. Detaille. (*Silicates Indust.*, 1958, **23**, March, 131–136). [In French]. The physical constants of materials important in relation to their ability to resist thermal shock, and the functional form of the characteristics of shock resistance are discussed. These considerations are then used in an analysis of the resistance to thermal shock of silica and silica-alumina bricks tested by the author.—P. F.

Certain Physico-Chemical Aspects of the Corrosion of Refractories. G. van Gijn. (*Silicates Indust.*, 1958, **23**, March, 137–139. [In French]. Some physico-chemical aspects of the attack of liquid slags on porous bodies and refractories are examined.—P. F.

The "Petrurgic" Processing of Austrian Basalts into a High-Wear-Resistant Material. E. Eipeltauer and F. Thenner. (*Radex-Rundschau*, 1958, (5), 224–234). "Petrurgy" is a rather new silicochemical-technological field concerned with the melting and casting of rock. Fused-rock bricks on a basalt base have an extremely high resistance to abrasion and wear and are far superior to steel in this respect. Raw materials used, melting, additions (for eliminating shrinkage cavities and improving the recrystallization), casting, mechanical and X-ray analysis and wear testing are described.—T. G.

Simultaneous Heating and Press Forming of Carbon Products in Minutes. (*Ind. Heat.*, 1958, **25**, March, 586–592). By modifying the method of blending the mix, electrical resistance between particles is lowered. Electric baking during pressing is then possible producing carbon products of high uniformity and low permeability.—A. G.

The Spalling of Silica Bricks. J. Hargreaves. (*Trans. Brit. Ceram. Soc.*, 1958, **57**, May, 242–257). Critical heating rates for 15 types of brick have been measured and the variations are attributed to the content and form of the Al_2O_3. Application of the results to the O.H. furnace is discussed.

IRON AND STEEL GENERAL

The Progress of Automation in the British Steel Industry. (*Autom. Prog.*, 1958, **3**, Aug., 288–290, 309). Strip thickness gauging and continuous casting are reviewed. Other operations, still in the development stages, are briefly considered.

India's Steel Giants. K. P. Ghosh. (*Far East Trade*, 1958, **13**, Aug., 1030–1031). Notes on recent construction, especially under Russian contracts, are given. Costs and attitudes are discussed.

New Adventure of India's Iron and Steel Industry. (*Iron Steel Rev.*, 1958, **2**, June, 41–50). A review of Indian works with statistics and a list of products and an account of current projects as well as raw material supplies for them.

India's Iron and Steel Industry Grows. (*Engineering*, 1958, **186**, Aug. 15, 206–207). Work of the British Consortium (ISCON) and training of Indians in the U.K. are described.

Chinese Steel Expansion. (*Met. Bull.*, 1958, Sept. 2, 11–15, 18). A survey with map.

China—A Steel Power? (*Far East Trade*, 1958, **13**, Aug., 1036–1038). Statistics of production and plans for extension are noted.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Ironmaking in the USSR—Impressions Gained from Visits and the Literature. E. W. Voice and S. Klementaski. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 218–235). The authors present some impressions of the Russian ironmaking industry, based on experience of British missions to the U.S.S.R. supplemented by information from recent technical literature and private communications. They deal firstly with the development of the industry, and then discuss blast furnace design and practice. Finally they consider the validity of Soviet literature, and give an outline of research facilities.—G. F.

Colossus at Port Kembla. (*B.H.P. Rev.*, 1958, **35**, Apr., 16–17). A description of No. 4 blast furnace.

Smelting Pig Iron with Low Manganese and Phosphorus Contents. B. N. Zherebin, V. P. Dembovetskii, V. M. Minkin and I. D. Nikulinskii. (*Stal'*, 1958, (7), 578–585). Work at Kuznetsk is described. Mn additions were eliminated and its effects in the blast furnace in relation to slag formation and sulphur removal are discussed.

Smelting Titaniferous Ores. H. U. Ross. (*J. Met.*, 1958, **10**, June, 407–411). The author shows that the smelting of titaniferous ores has been greatly simplified by recent developments in ore beneficiation and external desulphurization of hot metal. These techniques, coupled with correct slag and temperature control and favourable conditions in supplying the raw materials to the blast furnace, make the treatment of these ores both technically possibly and economically feasible.—G. F.

Humidified Blast Furnace Operation. B. J. Wilson. (*J. Met.*, 1958, **10**, Apr., 268–271). The author describes the operating characteristics of No. 5 blast furnace at Indiana Harbor when using higher blast temperatures and added moisture, and compares its performance with that of an identical sinter furnace. The benefits attributed to steam are improved hearth temperature control and increased driving rate, leading to an increase in production of 5–7% with little or no increase in coke rate.—G. F.

Blast Furnace Top Construction. H. M. Kraner. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 4–8). The author illustrates some of the currently used designs of blast furnace top sections, showing in each case the positions where the greatest wear occurs. He considers that further improvements in conventional top designs will require consideration of design features that will stabilize the structures.—G. F.

A Note on Bosh Construction and Bosh Tuyeres. G. D. Elliot. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 14–20). The author considers the practical and theoretical reasons for using a bosh in a blast furnace, and goes on to describe the method of bosh construction adopted at Appleby-Frodingham. Next he discusses the use of bosh tuyeres, again describing the installation at Appleby-Frodingham, where 10–12% increase in production has been obtained.—G. F.

Tuyere Development at Bethlehem. L. W. Butz. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 23–26). The author describes the developments in tuyere design which have taken place at the Bethlehem Steel Co., and illustrates the latest designs which have resulted in tuyere lives exceeding 400 days.

Stack Cooling Plates at Gary Works. J. W. Duncan and R. E. Turman. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 10–13). The authors outline operating experiences with stack cooling plates on the Gary Works blast furnaces, and give details of the location and arrangement of the plates. They conclude that cooling plates will extend the furnace life and will tend to retain more functional working lines.—G. F.

Desulphurization of Blast Furnace Iron with Injected Calcium Carbide. D. E. Wat-

kins and J. R. McFarland. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 202–208). At the U.S. Pipe and Foundry Co., blast-furnace iron is desulphurized by injection of CaC_2, using a technique developed by Air Reduction Co. The injection apparatus is described and typical results are quoted.—G. F.

Desulphurization of Molten Iron. J. N. Homak and E. J. Whittenberger. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 189–201). The authors discuss the desirability of externally treating molten iron for removal of sulphur, considering separately the desulphurization resulting from the composition and cooling of the iron, and that resulting from reaction with liquid or solid desulphurizing agents. They go on to describe the development of a successful injection technique, employing solid reagents such as calcium carbonate, burnt lime, calcium cyanamide, and calcium carbide.—G. F.

Application of Theoretical Principles to Desulphurisation in Iron and Steel Making. J. F. Elliot. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 173–181). The author discusses present-day understanding of some of the underlying principles of desulphurization, quoting 15 references. He considers the behaviour of sulphur in liquid iron-base alloys, the effect of composition on the desulphurizing capacity of slags, and the application of these theoretical considerations to the blast furnace, the O.H. furnace, and to various external desulphurizing processes.

Desulphurization with Calcium Cyanamid in Hot-Metal Ladles. G. G. Hatch, G. E. Wagner and M. Trottier. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 184–188). Hematite–ilmenite ores are smelted in electric furnaces at Quebec Iron & Titanium Corp. to produce an iron containing 1%C and 0·6%S. Brief details are given of a series of plant-scale ladle-desulphurization tests employing calcium aluminate, calcium silicate, sodium hydroxide, and calcium cyanamide as desulphurizing agents. The last-named is the most efficient, reducing sulphur content to less than 0·035%. Temperature control is found to be necessary.

Slag-Metal Reactions of Chromium in Carbon-Saturated Melts. C. W. McCoy and W. O. Philbrook. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 50–57). From a series of laboratory studies, the authors give a general picture of the behaviour of Cr in distributing itself between slag and metal under the low oxygen pressures that prevail for carbon-saturated iron and blast-furnace-type slags. The information offers a rational explanation for the relationship between Cr distribution and the content of Mn or Si observed by previous investigators.—G. F.

Equilibria of Molten Iron and Liquid Slags of the System CaO–SiO_2–$(FeO)_t$. H. L. Bishop jun, N. J. Grant, and J. Chipman. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr., 185–192). A description is given of a series of experiments in which molten iron and liquid slags containing iron oxide and sulphur were equilibrated with lime and dicalcium-silicate crucibles. The distribution of oxygen and sulphur is discussed, and the solubility of lime in liquid iron oxide is established. The 1600° C isotherm for the compositions of liquid lime-silica–iron oxide slags in equilibrium with molten iron and the crystalline phases lime and dicalcium–silicate is also presented.—G. F.

Rate of the Carbon-Oxygen Reaction in Liquid Iron. N. A. Parlee, S. R. Seagle, and R. Schuhmann jun. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 132–138). The authors have determined the rates of evolution and absorption of CO for liquid iron alloys containing 0·15–4·4%C, held in alumina crucibles in a modified Sieverts apparatus. The data are interpreted on the hypothesis that the C–O reaction rate is controlled by oxygen diffusion across the boundary layers at the gas-metal and crucible-metal surfaces.

The Low-Shaft Furnace. M. Allard. (*Iron Coal Trades Rev.*, 1958, **176**, June 27, 1563–1565). The history of the low-shaft furnace is outlined and the installation at Ougrée is described. Conditions favouring the low-shaft furnace are listed.

An Orifice Gas Washer. J. R. Lowe. *A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 28–30). A description is given of the orifice gas washer unit installed in the blast-furnace plant at Jones and Laughlin Steel Corp., Pittsburgh. The average dust content of the washed gas is 0·032 grains/ft³ and similar installations on other furnaces are planned.—G. F.

Pig-Iron Production in the Electric Furnace. C. E. Lesher. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 60–71). The author first discusses the economic and technical conditions and circumstances at present surrounding the production of pig iron, and then goes on to consider the possibilities of electric smelting with pre-reduction of the ore in a rotary kiln. Material and heat balances for each step are given, and details are given of the "Orcarb" process for agglomeration of fine ores with low-temperature coke. Finally the economics of electric smelting are considered and shown to be competitive with those of the modern blast furnace.—G. F.

Hot-Metal Pre-Treating Tower. J. W. Gaines and D. C. Hilty. (*J. Metals*, 1958, **10**, July, 452–455). To take full advantage of the improvement in steel production attainable by preliminary removal of silicon from the iron, without the attendant disadvantages of ejection of metal and heavy fuming, a shot tower has been developed. The iron breaks up into droplets, and thus exposes a large surface to the action of a stream of oxygen. The work described is on an experimental scale, but results obtained were considered to be encouraging, although data are incomplete.—G. F.

New Methods in Pig-iron Manufacture. A. N. Pochwisnew. (*J.I.S.I.*, 1958, **190**, 337–338). (This issue).

Unconventional Iron Smelting Processes. M. O. Holowaty and C. M. Squarcy. (*J. Metals*, 1958, **10**, July, 456–459). A brief review is given of the history of the development of modified blast-furnace and direct reduction processes.

PROPERTIES, TREATMENT, AND USE OF SLAGS

On the Construction and the Behaviour of Constituents in the Molten Slag of the Fundamental System. R. Sakagami and Y. Matsushita. (*Report of the Institute of Industrial Science, University of Tokyo*, 1958, **7**, Mar., pp. 45). [In English]. Measurements of e.m.f. and of decomposition voltages are made and the reactions concerned are formulated. Activities are calculated for SiO_2 and CaO and the amphoteric nature of Al_2O_3, MgO and TiO_2 is shown. Conclusions on sulphur removal and other aspects of steel making are drawn, including slag basicity.

Structural Basis of the Absorption Capacity for Sulphur of the Liquid Metallurgical Slags. T. Negrescu. (*Met. Constr. Masini*, 1958, (2), 97–108). A continuation of the article which appeared in the preceding number and deals with the action of cations in the desulphurizing process in liquid slags. Some general expressions are derived and nomographs are given for this absorptive capacity.

Reactivity of the Constituents of Metallurgical Slags. T. Negrescu. (*Rev. Mét. Bucarest*, 1958, **3**, (1), 5–40). [In Rumanian]. This article summarizes 10 years' research in this domain which in the main can be divided into two sections, one, concerning the constitution and the oxidizing properties of the slags, and the other, the desulphurizing capacity. Whilst studying their behaviour to sulphur and oxygen, the author has indirectly discovered the presence in these liquid slags of new ionic groupings, given by the formulæ $4MgO,5SiO_2$; $3FeO,8SiO_2$; $3MnO,10SiO_2$ and $BaO,3SiO_2$.—L. H.

The Desulphurising Property of Blast-Furnace Slags. VII. Absorptive Capacity for Sulphur of Slags of the System SiO_2–CaO–BaO in the Liquid State at 1500° C. T. T. Negrescu. (*Studii si Cercetari de Metalurgie*, 1957, **2**, (4), 441–463). Previous investigations over a number of years have established the maximum amount of sulphur which blast-furnace slags can absorb under equilibrium conditions in the presence of a liquid bath, and a formula has been derived which gives results in agreement with practical experience.—L. H.

Experimental Investigation of the Viscosity of Open Hearth Slags. I. Tripsha. (*Rev. Mét. Bucarest*, 1958, **3**, (1), 41–59). [In Russian]. The viscosity at 1600° during the finishing period can be calculated from an empirical formula given by T. Negrescu. It has been established that the specific conductivity grows with increasing temperature, proving its ionic character, and the existence of a relation between this conductivity and the viscosity of the slags has also been demonstrated.—L. H.

The CaO–MgO–SiO_2–Al_2O_3–Cr_2O_3–Fe_2O_3 System. W. F. Ford and W. J. Rees. (*Trans. Brit. Ceram. Soc.*, 1958, **57**, May, 233–241). The system is of some importance in refractories and in high-Cr steel slags.

DIRECT PROCESSES

Carbon Monoxide Reduction of Iron Ore. O. Stelling. (*J. Met.*, 1958, **10**, Apr., 290–295). The author describes the development of a process of continuous direct-reduction of iron ore, using CO in a fluidized bed. Laboratory and pilot plant experiments are discussed, and the advantages of the method over the Wiberg-Söderfors method of making sponge iron are outlined.—G. F.

Electrolytic Production of Hydrogen. A. E. Zdansky. (*Iron Coal Trades Rev.*, 1958, **177**, Aug. 1, 279–280). A pressure method is described as a possible source for direct-reduction process fuel.

R–N Direct Reduction Process. A. Stewart and H. K. Work. (*J. Metals*, 1958, **10**, July, 460–464). The direct reduction process developed jointly by the Republican Steel Corporation and National Lead Co. during the past 13 years is described and discussed in detail. The process is suitable for U.S. ores, either high-grade or with iron contents as low as 25%. Crushed and sized ore or balled fines are treated with an excess of solid fuel in a gas or oil-fired kiln, and the product is subsequently concentrated. The uses of the material produced and economic aspects of the process are discussed.

The H-Iron Process. A. M. Squires and C. A. Johnson. (*A.I.M.M.E., Blast Furn. Comm. Proc.*, 1957, **16**, 32–42). The authors describe the "H-Iron" process for the direct reduction of iron-ore fines with H_2 in fluidized beds, operating at relatively low temperatures (below 1000° F) and at elevated pressures (above 200 lb/in²). The principles of the process and the experimental plant at Trenton are described in detail, and the use of H-iron in O.H. and electric steelmaking at Bethlehem Steel Corp. is discussed. Finally, the economics of the H-Iron process are considered.

Iron and Nickel by Carbonyl Treatment. R. M. Lewis, J. W. Cookston, L. W. Coffer, and F. M. Stephens jun. (*J. Met.*, 1958, **10**, June, 419–424). The authors have investigated the possibilities of extracting iron and nickel from lateritic deposits by carbonyl treatment, involving hydrogen reduction of the ore followed by treatment with ammonia and then carbon monoxide under pressure. Thermodynamic studies and laboratory experiments are described and it is concluded that the process is technically feasible and capable of high iron and nickel recoveries.

PRODUCTION OF STEEL

New Developments in Steelmaking Processes. D. L. McBride. (*J. Met.*, 1958, **10**, Apr., 263–267). The author discusses some of the recent developments in blast furnace operation; O.H. steelmaking, including oxygen lancing and all-basic construction; the pneumatic processes; electric furnaces; and the application of automatic controls. He stresses that the economic aspects of each process, combined with the availability of raw materials, will govern the extent to which it becomes established.—G. F.

Oxygen in the Iron and Steel Industry of the U.S.S.R. V. V. Kondakov. (*Kislorod*,

1958, (3), 1–10). A review of the use of oxygen in the blast furnace, converter, O.H. and electric furnaces with some case history data is given, with a brief review of some of the economic factors.—R. S.

Oxygen Production. E. G. Hickling and A. E. Hittl. (*Welding J.*, 1958, **37**, July, 700–701). A brief outline is given of the production cycle in the manufacture of 99·5% purity oxygen by the liquefaction process.

The Future of Oxygen in Steel. E. Ford. (*Brit. Steel.*, 1958, **24**, July, 208–210). The advent of "tonnage oxygen" is likely to have a far-reaching effect on the steel industry. The author discusses the technical advantages of using O_2 in the steelmaking process, mentioning some of the new Continental techniques including the L–D, Rotor, and Kaldo processes. The question of economics is considered, and possible alternative methods of supply are mentioned.—G. F.

Thermochemistry of Oxygen Steel. W. O. Philbrook. (*J. Metals*, 1958, **10**, July, 477–482). Basic oxygen steelmaking is shown to be versatile, and is capable of using a very varied proportion of scrap. Its economic possibilities, particularly with regard to the burning of CO in the exhaust gases, have not been fully explored.—L. D. H.

Largest On-Site Oxygen Plant to Serve Four U.S. Steel Works. (*Ind. Heat.*, 1958, **25**, July, 1397–1398). A 1000-t/day plant at Duquesne Works is described.

Risco's £8,000,000 Expansion Plans. (*Rhodesian Mining and Engineering*, 1958, **23**, June, 41–43). Plans for Redcliffe and Bulawayo are briefly outlined, with a list of the contractors.

The Use of Oxygen in Small Converters. B. A. Andreev. (*Lit. Proizv.*, 1958, (3) 4–7). Experiments under industrial conditions have led to the formulation of a pig iron of the following composition for refining by oxygen blowing: 2·6–3·4%C; 0·6–1·0%Si; 0·5–0·8%Mn; 0·05–0·08%P; 0·05–0·06%S. Castings from the steel so obtained, after mechanical treatment, possess a compact structure and show no defects when cast for the main parts of cable machines, which, without tempering and normalizing, give satisfactory service.—L. H.

Oxygen-blown Basic Steelmaking. (*Iron Coal Trades Rev.*, 1958, **177**, Aug. 1, 280). A brief note on the Aliquippa L–D converter installation.

Properties of Metal Produced by Top Blowing with Oxygen. P. Ya. Ryzhkov, A. A. Mitrofanov, N. I. Beda and G.L. Livshits. (**Stal'*, 1958, (7), 643–647). Experiments at Petrovsk have shown that steel equal to O.H. steel can be obtained. No differences were observed in gas content, macro- and microstructures or weldability. The properties of the steel are given.

"O.L.P.": Oxygen, Lime-Powder Injection. A New Steelmaking Process. B. Trentini and M. Allard. (*J. Metals*, 1958, **10**, July, 486–470). A description of the process developed by IRSID, in which pig iron is dephosphorized by injection of lime powder suspended in a jet of oxygen. The operating technique applied to 1·8%P iron is described. Low S and N are also obtained. Application to low P iron (about 0·2%) is also described.

Sulphur Removal from Mild Steel in the Basic Open Hearth Furnace. T. Fujii. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 969–972). The changes with time of the S and C contents, the rate of S removal and the (S)/[S] and CaO/SiO_2 ratios are traced, and variations in slag composition are shown on a ternary diagram.—K. E. J.

Behaviour of the Sulphur in Oil During the Charging and Melting Periods. K. Maeda. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 972–973).

Study on Problems of the Last Stage of the Melting Period. Deciding the Starting Point of the Refining Period. M. Yamamoto. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1042–1043). Slag conditions are discussed, and a nomograph is presented for deciding when to start melt-down from the bath temperature and carbon percentage.—K. E. J.

New Methods of Studying Equilibrium in Metal-Slag Systems. V. F. Surov, O. V. Travin and L. A. Shvartsman. (*Problems of Metallography and Metal Physics, 4th Collection of Papers*, 1955, 616–620). A tracer method using ^{35}S and ^{32}P is described.

The Kinetics of Sulphur Transfer from Pig Iron to Slags of the System CaO-Al_2O_3. O. V. Travin and L. A. Shwartsman. (*Zhur. Fiz. Khim.*, 1955, **29**, (11), 2031–2041). [In Russian]. The experiments were made in graphite crucibles placed in the secondary of a transformer and protected by an atmosphere of N_2. The results bear on the desulphurization of iron by slag of the system CaO–Al_2O_3 at various temperatures and under various concentrations of S, Si and Mn in the metal. It has been found that the speed of desulphurization is proportional to the concentration of S in the iron and that it is a function of the temperature.—L. H.

On the Slag Control of Basic Open-Hearth Production of Killed Steel. F. Ono. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1039–1041).

The True Function of Manganese in the Basic Open-Hearth Steelmaking Process. J. Natkaniek. (*Hutnik* (*Poland*), 1954, **21**, (10), 329–335). A study of the reactions of Mn in the O.H. furnace, its role as deoxidant and effects of slag basicity are reported. Working conditions for Mn economy are derived.

Reduction of Silicon by Carbon under Varying Pressures of the Gaseous Phase. I. P. Bardin and V. M. Shchedrin. (*Izvest. Akad. Nauk Otdel. Tekn.*, 1957, (11), 27–43). The partial CO pressure greatly influences the beginning of the thermal reduction of Si by C. SiO_2 is reduced first to SiO and regeneration of CO is brought about by the carbon and completes the decomposition of SiO on the surface of the carbon with the liberation of the free Si. This reaction is studied in this article in relation to the temperature as regards SiO_2 and as regards Si in solid solutions.—L. H.

Oxygen in the Metal in Acid Open-Hearth Melting. M. M. Karnaukhov and A. Kh. Urazgil'deev. (*Izvest. Akad. Nauk Otdel. Tekhn.*, 1957, (10), 47–54). [In Russian]. In the investigation described, samples of metal were taken at various stages of the acid O.H. process and analysed for oxygen; at the same time slag and metal samples were taken for chemical analyses and metal temperatures were measured. It was found that the O_2 contents during the boil were always lower than in basic furnaces for the same carbon concentrations, and were determined mainly by the carbon concentration being well below that in equilibrium with the Si. The O_2 content after deoxidation first fell and then rose. It is suggested that, in a duplex (basic-acid) process, some ore should be added to the acid furnace before the hot metal.—S. K.

Electronic Automatic Control of Open Hearth Furnaces. P. G. Baranovski and Ya. S. Pinus. (**Metallurg*, 1958, (2), 15–17). A flexible, reliable and simple programmed control of mixed-gas-fired furnaces at Kuznetsk (Siberia) is described. It enables maximum heat input to be maintained for each period of a heat. Automatic correction of gas and air feed and of the entire thermal conditions is based on two factors: temperature and the rate of heating of the outgoing products of combustion and the temperature of the top of the checkers.—R. S.

Production of Ball Bearing Steel in an Acid Furnace Fired with Natural Gas and Heavy Fuel Oil. A. A. Kisselev, M. P. Lipshova and M. N. Kul'kova. (*Stal'*, 1958, (1), 35–40). Change over from Si reduction to the acid furnace method increased purity, reduced sulphides and oxides and reduced tap-to-tap time by 35 min. Tapping temperature should be controlled to between 1580°–1600°, reduced Si kept below 0·23% (which is the upper limit), and iron oxide in the slag before deoxidation should be 15–20%. If Si–Zr is used in the ladle, rejects for oxide inclusions fall by 0·35–0·6% and for sulphides rise 0·2–0·3%. The electrolytic method gives more inclusions than does Al reduction. Si-Zn gives a low spinel content. Rejects for oxide inclusions increase with spinel content and with Al_2O_3/SiO_2 ratio; increased iron oxide in the slag before deoxidation raises these contents. Relations to tapping conditions are also given.—R. S.

Production of Tube Steel by the Scrap and Ore Process Based on Low-Manganese Pig Iron Under Different Conditions of Adding Manganese. A. I. Pastukhov, K. M. Petrov and A. M. Danilov. (*Stal'*, 1958, (1), 28–34). Omission of ferromanganese has no deleterious effect on steel quality and cuts down tap-to-tap time and reduces Mn consumption. Addition of Fe-Mn does not protect the boiling bath from over-oxidation and does increase non-metallic inclusions. Using the process with low-S fuel and a normal pure boil does not reduce dephosphorization or desulphurization nor do tensile or ductile properties deteriorate even down to −60° C. It is shown to be unnecessary to control Mn content during the heat and even during the pure boiling period.

Study on the Pressure Loss and Heat Transfer in the Packed Column from the Metallurgical Standpoint. N. Nakamura, R. Ichiyasu and Y. Sato. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1089–1093). Experimental results on air and magnesia clinker packing yield formulæ applicable at room temp., 300° C and 450° C for Reynold's numbers in the range 40–500. Heat-transfer was explained in terms of Kuzuoka's equation.—K. E. J.

The Effect of Si, Cr and Mn on the Equilibrium of Carbon and Oxygen in Molten Iron Saturated with Carbon. II. S. Ban-Ya and S. Matoba. (*Technology Reports of Tōhoku Univ.*, 1957, **22**, (1), 97–108). White pig iron melted with graphite to saturation was cast and the other elements were added. The samples were melted in an induction furnace flushed with CO and equilibrium was established (2h). The charge was quenched in cold N_2, freezing in 10–15 sec and analysed. Curves and empirical formulæ for carbon solubilities are given.

Relation Between the Desulphurization and Deoxidation of Steel. Z. Buzhek and A. M. Samarin (*Izvest. Akad. Nauk, Otdel. Teckhn.*, 1957, (9), 37–44). [In Russian]. In the investigation described, the mutual effects of deoxidation and desulphurization in a slag/steel bath at different temperatures was studied on a 40-kg scale. An induction furnace was used, a graphite lid serving to heat the slag layer by radiation. The metal charge (C < 0·1%; Si, 0·04%; Mn, 0·34%; Cu, 0·12%; Ni, 0·11%; S, 0·033%; P, 0·022%) was covered with a synthetic slag (15% Al_2O_3, 45% CaO, 70% SiO_2). It was found that the introduction of Si and Al accelerates desulphurization, this effect increasing with rising temperature. Desulphurization and deoxidation were found to proceed simultaneously, the sulphur leaving with the deoxidation products.—S. K.

The Electric Furnace—Creative Inferno. N. H. Keyser. (*Battelle Tech. Rev.*, 1958, **7**, Mar., 3–7). Electric furnace steel, pig iron and ferro-alloys are briefly referred to.

Economic Future of the Large Electric Arc Furnace. W. B. Wallis. (*Iron Steel Eng.*, 1957, **34**, Dec., 110–113). The author discusses the economics of operating arc furnaces of capacities ranging from 125-t to 250-t. Some mechanical and operating data are given. It is suggested that the use of hot metal in arc furnaces may come to be normal practice where iron making facilities are available.

Large Modern Arc Furnaces Used in the Iron and Steel Industry. M. Petitdidier. (*J. Four. Elec.*, 1958, **63**, Jan.-Feb., 19–26). A brief historical outline with an account of the increases in size and capacity is presented. Construction is outlined and the economics of operation are briefly discussed. (32 refs.). Notes on the Düsseldorf Conference are added (p. 31).

A Modern Arc Furnace for Steelmaking. A. Cella. (*Fonderia*, 1957, **6**, Nov., 474–478). [In Italian]. The article gives details of a recently installed 22-t arc furnace with a maximum power input of 9,000 kW and 20,000 A current at the electrodes. The melting time is given as 90 min for a scrap charge of 22 t. Technical and operating data are given.—M. D. J. B.

Southern Hemisphere's First Large Arc Furnace. (*Eng. Foundryman*, 1957, **22**, Dec., 35–36). A brief account of the 70-t furnace commissioned by ISCOR is given.

Increasing the Life of Banks of Electric Furnaces. O. F. Antropov and N. V. Sidorov. (*Stal'*, 1958, (1), 48–49). Trials were made in 10-t electric furnaces of three types of magnesite blocks whose properties are given. Various proportions of one or other type were used. A dense brick, with raising of the banks 130 mm above the existing level was found to increase wall life.—R. S.

On the Application of Induction Stirring in Steel-making Practice with an Electric Arc Furnace. S. Nishigori. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1043–1045).—K. E. J.

Intensification of the Oxidising Period in the Production of Structural Steel in the Electric Furnace. F. P. Edneral and N. F. Khlystov. (*Stal'*, 1958, (1), 43–48). Addition of 3% lime and the use of a 5-min O_2 blow (~600 m³/h) at the end of melt-down produces fairly complete dephosphorization. Slag basicity of not less than 2·2 at melt-down at ~1500° C is recommended. During the O_2 boil more P is removed and the slag basicity should be 2·6–3·0. The rate of C drop in a 20-t furnace with O_2 at 900 m³/h and 10 atm. with 0·8–1·0% C is 3% C per h. To ensure heating up to 1610°, 0·5% C must be oxidized at 0·05%/min. The oxidation period was reduced by 30% in trial heats. More rapid analysis for C content might reduce it further.—R. S.

Possibility of Surcharging Electric Arc Furnaces. E. I. Astrov. (*Metallurg*, 1958, (1), 21–22). The effective utilization of arc furnaces built 15 to 20 years ago and equipped with low-capacity transformers is of prime importance in increasing the output of electric steel in Russia. The main factor is the correct ratio between transformer capacity and furnace dimensions. While it is entirely justifiable to increase transformer capacity for old furnaces, this is not as practical as an increase in furnace charging capacity. A formula is discussed for calculating the optimum extent of surcharging. It is often considered in practice irrational to overload the furnace by more than 30 to 50%. Tap-to-tap time can, however, be reduced by replacing hand charging by basket charging and by oxygen lancing. Improvements can also be effected by correct charging and quality of the charged materials, proper electrical and thermal control and improved refractories. Some data are given showing improvements effected from 1951 to 1955. Shell diameter was increased by 9 in., basket charging reduced the charging period from 75 to 13 min, segments were used for lining the walls and magnesite-chrome brick was used for the roof. Ladle capacity was increased and launders were widened.—R. S.

Saturable Reactor Control of Electric Furnaces. R. M. Sills. (*Ind. Heat.*, 1957, **24**, Oct., 2028–2030, 2032, 2034, 2036; Dec., 2473–2474, 2476, 2478, 2480, 2482). Various applications of the system are described, not all metallurgical. Circuits and electrical characteristics are shown for the various purposes.

Not to be Neglected: Steels with Many Purposes. (*Edgar Allen News*, 1958, **37**, Apr., 73–75; Carbon tool steels are reviewed.

Erosion Estimation on the Ladle Nozzle by a CoO Tracer. S. Katsube. (*Tetsu-to-Hagane*, 1957, **43**, 1028–1030).—K. E. J.

The Effects of Deoxidation by Silicon-Manganese on the Composition of Steel with Optimum Mechanical Properties. W. A. Mczedliszwili and A. M. Samarin. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, (3), 93–124). [In Polish]. This paper is a result of collaboration of the Institute of Metallurgy in Moscow with the Institute in Sliwice (Poland).

Large-scale experiments were conducted (in the laboratory and in industry) to investigate methods of preliminary deoxidation of steel in the O.H. process in order to obtain products with minimum inclusions and the best mechanical properties. The influence of the composition of Si-Mn on the amount and nature of inclusions and the properties of steel were examined. The methods of study used are described and the results tabulated and illustrated with micrographs. The investigations show that the best results are obtained when a Si-Mn with a ratio of 6 : 1 was used.

Some Studies on Ingot Moulds. K. Sasaki. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1049–1051).

Casting Ingot Moulds from Liquid Pig Iron. P. V. Gubchevskii (*Metallurg*, 1958, (1), 3–5). One of the difficulties in the manufacture of ingot moulds from liquid pig iron is the presence in the liquid hypereutectic pig iron of coarse graphite foam. This led to the abandonment of experiments started in 1936 in Kuznetsk. These experiments were, however, continued later in Siberia and in 1947 Magnitogorsk stopped producing ingot moulds made of cupola iron and began to make ingot moulds from steel-making grade pig iron. This method is now suitable for most plants. The cost of the requisite ladle-tilting equipment is recouped in three months in a mould shop with an output of 20,000 t a year and in a single month in a 60,000 t a year shop. When the Kuznetsk mould plant changes over from cupola to blast furnace iron for ingot moulds, they will save 5,000,000 roubles a year.

Pig iron ingot moulds are cheaper than cast iron moulds and have longer lives. The pig iron analyses C 4·0–4·3, Si 0·6–1·5, Mn 0·5–1·8, S 0·05 and P 0·18%.—R. S.

A New Design of Ingot Mould. A. S. Korzhavin. (*Metallurg*, 1958, (2), 18–19). The top 12 in. of the new mould has parallel sides with a major axis taper of 2·1% and a minor axis taper of 4·6%. The corners are fluted with two convex radii of 80° and a central concave radius of 100° (at each corner). The mould has a "wine glass" bottom. Seven tube steel ingots were bottom poured and rolled into 1 in rounds. These exhibited longitudinal cracks in one case only. In the soaking pits, the difference between face and corner temperatures was only 40° C in the new ingots compared with 125° C for normal ingots. Rejects were halved with the new ingots and bottom discard was 1·5% instead of the normal 3%. Mould life was comparable to that obtained with the conventional design.—R. S.

On Thermal Balancing of Steelworks Moulds. J. Přibyl. (*Hutník*, 1958, **8**, (1), 2–5). [In Czech]. The assessment of steelworks mould life from the mould-ingot weight ratio is inaccurate, but could be of substantial value with moulds shaped so as to give a uniform surface temperature distribution in the range 650–750° C in which the expansion of the cast iron is greatest. Researches which could lead to a better thermal balancing of moulds than the empirical methods generally used are discussed.—P. P.

Cracking and Life of Ingot Moulds. J. Duflot. (*Trans. A.F.S.*, 1956, **64**, 387–397). Data from French basic Bessemer plants show the desirability of having the ratio of mould weight to ingot weight low for 3–5 t ingots, (about 1). These light moulds tend to crack and possible causes are discussed. In general, the hottest parts of the mould tend to crack, but pouring practice plays a part and it is possible that composition does also.

Deoxidation of Rail Steel With Less Aluminium. N. I. Shirokov and B. G. Petukhov. (*Metallurgy*, 1958, (1), 17–21). When rail steel is deoxidized by FeMn only in the furnace and with a substantial amount of 45% FeSi containing 1% Al in the ladle, it is advisable to reduce the amount of Al added to 200 g/t of steel so as to reduce the consumption of Al, to lower steel costs and to improve mechanical properties of the rails.

Improving the Technology and Casting of Rail Steel. M. N. Kravets. (*Stal'*, 1958, (1), 40–42). Viscosity at teeming should be lowered, even increased speed of uphill casting does not remove the drawbacks of low temperature. At 1470°–1490° C pouring through a 46–47 mm dia. trumpet is satisfactory. Control of rate of pouring during the initial period of filling of the body of the ingot mould improves metal quality, the slower the bottom is filled the less the porosity of the finished rail. Increase of pouring rate does not reduce rejects for porosity, seams and fine cracks. When the moulds were coated at 60–80° C porosity is markedly reduced. Use of a trumpet for uphill casting reduces the rate of pouring.—R. S.

The Imatra Thermit Hot-topping Process. A. I. Aitken, W. C. Fletcher, and G. Fenton. (*J.I.S.I.*, 1958, **190**, Dec., 340–359). (This issue).

Studies on the Ingot Making Process in a Nitrogen Atmosphere. II. T. Shimose, H. Hirano and K. Katiuti. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1111–1122). The process gives a cleaner surface appearance to rolled billets, and no sub-surface defects. Internal and external gas contents and grain sizes are comparable with those from ingots made normally. Some theoretical aspects of oxidation and N_2 absorption in the molten steel are considered. (29 references).—K. E. J.

Continuous Casting. A. N. Myasoedov. (*Lit. Proizv.*, 1957, (12), 1–3). The investigations included non-ferrous metals, iron and steel. Since the success of this method of casting is based on the rapid crystallization of the cast metal so as to promote fine grain structure, extensive tests have been carried out with cooling arrangements. Many alternatives have been investigated and the results obtained are set out in detail.—L. B.

Continuous Casting of Steel. (*Engineering*, 1958, **185**, Mar. 7, 293–294). An account of the plant built by Damag for Terni Società per l'Industria e l'Ettricita, Terni, Italy.

A Modern Swedish Steelworks. (*Machinery*, 1958, **92**, Apr. 11, 846–847). A brief illustrated account of the continuous casting and stainless steel cold rolling installation of the Nyby Bruks A.-B. is given.

Study on the Solidification Character of Rimmed Steel. J. Ooka. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1046–1048). Data are given for the temperature cycles in the ingot, the linear progression of solidification, and the solidification pattern of the upper part of the ingot.—K. E. J.

Studies on the Solidification and Segregation of Large Steel Ingots. IV. Behaviour of Segregates in Sand-cast, Leaning Ingots. S. Onodera. (*Tetsu-to-Hagane*, 1957, **43**, 912–913). [In Japanese]. The internal structure of an ingot which was tilted to an angle of approx. 25° to the vertical three times during solidification is studied by sulphur prints and macro-etching.—K. E. J.

Study on Ingot-Making Practice. V. Effect of Oxidation of Molten Steel by Air on the Non-metallic Inclusions in Steel. 2. Oxidation of Various Elements in Molten Steel and Effect of Casting Conditions on Oxidation. S. Maekawa and Y. Nakagawa. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1098–1104). Si, Mn, Al and Cr were oxidised by air during pouring in proportion to their contents in the steel before pouring. The amount of oxides formed during pouring are compared with those in the steel after pouring. Fast casting velocities minimize the formation of oxides.—K. E. J.

Rational Technology in a Modernised Iron and Steel Works. S. Rytwinski. (*Prz. Techn.*, 1957, **78**, March, 201–203). [In Polish]. New methods of preparation and preliminary treatment of steel ingots and the problem of economy in the steel industry achieved by reducing the cost of labour and reducing the amount of coal used are discussed.

Effect of Track Time on Semi-Killed Steel Ingots. M. Katayama. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1048–1049). [In Japanese].

Some Studies on Semi-killed Steel. I. Correlation between the Degree of Deoxidation and the Formation of Blow-Holes. T. Kato. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1104–1111). Studies on test ingots weighing approx. 4-t were made to relate the degree of deoxidation with the number, size, position and distribution of blowholes. The steel contained 0·16–0·25% C and 0·34–0·54% Mn. As well as deoxidation, the H_2 content plays a large part in blowhole formation: it reaches 60% in the gas when deoxidation has been taken so far that almost no blowholes are formed. (13 references).—K. E. J.

Study of Non-Metallic Inclusions The Origin of Sand Marks. I. M. Kawai. **II.** H. Kimura. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1051–1053; 1053–1055). Numbers of sand marks of different sizes are shown for positions in ingots of different forging ratio. Similar data are given for rods and bars of various sizes.—K. E. J.

Reducing the Amount of Non-Metallic Inclusions in Rimming Steel. D. S. Gerchikov. (*Metallurg*, 1958, (1), 15–17). The main reasons for the contamination of rimming steel ingots were (1) elongated slag patches in the rimming metal in the mould; (2) residual manganese oxide in the metal; (3) refractory particles embedded between the growing crystallites. The following remedies were established: (*a*) deoxidation of the steel by FeMn in the ladle instead of in the furnace; (*b*) a tapping temperature of 1600–1620° C; (*c*) the use of a fluxing mixture of 65% dry sand and 35% by volume of mill/scale to thin the slag in the ingot mould.—R. S.

Influence of Casting Refractories on Impurities in Ball Bearing Steel. M. I. Vinogradov, M. A. Lyubinskaya and N. D. Orekhov. (*Metallurg*, 1958, (2), 12–15). High alumina (72–75% Al_2O) refractory with a porosity of 5·6 was found to be superior to fireclay and kaolin for lining ladles and runners for the production of ball bearing steel. Higher metal temperatures are associated with a greater degree of contamination.—R. S.

PRODUCTION OF FERRO-ALLOYS

The Air-Melting of Iron–Aluminium Alloys. V. F. Zackay and W. A. Goering. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr. 203–204). The authors have developed an air-melting technique for the production of ductile Fe–Al alloys containing more than 6% Al. The process involves the mixing of the two liquid metals, and requires drastic deoxidation and control of all stages of melting. Details of the technique and of the subsequent processing of the ingot are given.—G. F.

FOUNDRY PRACTICE

Foundry Practice. S. S. Singh Talujn. (*Iron Steel Rev.*, 1958, **2**, June, 35–39). A review of German practice and the possibilities of its adoption in India.

Metallurgical Progress in the Iron-Foundry. W. W. Braidwood. (*Engineer Foundryman*, 1958, **22**, Feb., 81–85, 92). Progress over the past 21 years is reviewed in the development of special irons and of melting techniques.

The Elimination of Unnecessary Transportation. W. Riege. (*Giesserei*, 1958, **45**, Aug. 14, 474–477). Layout and equipment of a foundry with short transport distances are described.—T. G.

Foundry Mechanization: Developments at the Farington Foundry of Leyland Motors Ltd. T. Kneale. (*Iron Steel*, 1958, **31**, Apr., 125–129). Recent mechanization at the Farington Foundry has covered sand reclamation and mixing plant, filling and ramming of moulding boxes, automatically operated airless shot-blasting plant, and complete reorganization and re-equipment of the greensand moulding plant. Details are given of the foundry layout and operations.—G. F.

Integrated Mechanization and Automation as the Determining Factor in Foundry Progress. D. P. Ivanov. (*Lit. Proizv.*, 1958, (5), pp. 1–2). The author examines the progress in foundry practice, especially in the last ten years, in terms of increasing mechanization and automation. He estimates that labour and floor-space productivities have risen by factors of 1·5–2 and 1·3–1·5, respectively, through mechanization and technical progress and that automation has secured a 3 to 4-fold rise in labour productivity. He suggests that the new decentralization of the industry provides better conditions for progress, but indicates that over 30% of the 20,000 moulding machines available are out of date and that the development of new types and the work of the Research Institute for Foundry Technology and Machine Construction are progressing inefficiently.—S. K.

Ways of Automatic Control of Casting Moulds on Conveyors. I. B. Zaigerov. (*Lit. Proizv.*, 1958, (3), 11–14). The automation of casting metal into the moulds is at present in its initial stages. Arrangements are here described which are needed for the verification of the experimental results so far attained which might form the basis for further improvements, and which are useful for an appreciation of the economics of the process.—L. H.

Quality of Coke for Cupola Use. N. N. Das Gupta and A. Lahiri. (*Iron Steel Rev.*, 1958, **1**, May, 23–29). An account of the properties required for cupola work and the properties and limitations of Indian cokes is given.

Some Cupola Studies. T. Ishino. (*Waseda Univ. Rep. Castings, Res. Lab.*, 1957, (8), Nov., 5–8). The effects of cupola design, coke size and air blast on cupola operation were investigated with the help of a model cupola.

Hot Blast For Small Foundry Cupolas. (*Mech. World*, 1958, **138**, Aug., 362–363). An oil-fired installation at Brierley Hill is described with an indication of the savings obtained.

Cadillac Shoots Cast Iron Chips into the Cupola. (*Mod. Castings*, 1958, **33**, June, 42). Relatively cheap equipment permits the injection of cast iron chips into the upper melting zone of the cupola. The process is attractive where machine shop turnings are available and heavy scrap is scarce.—A. G.

The Combustion of Coke and the Heat Exchange in Cupolas. L. Moraru. (*Met. Constr. Masini*, 1958, (3), 205–208). [In Rumanian]. The complete oxidation of C to CO_2 liberates 94·000 cal., to CO only 29·430. This study aims at determining the optimum conditions for the heat exchange in cupola furnaces for a maximum exothermal output.—L. H.

Cupola Charging: New Installation for Clarke Chapman. (*Iron Steel*, 1958, **31**, Apr., 150–151). Brief details and illustrations are given of the two new cupolas at the Gateshead foundry of Clarke Chapman & Co. Ltd. The main feature is a pivoted loading boom by means of which the charging skip can be directed to either furnace as required.—G. F.

Quality Control in Cupola Melting. R. A. Short. (*Can. Metalw.*, 1958, **21**, Mar., 30, 32, 34, 36). Limestone quality, scrap properties, temperature and humidity, coke inspection, mixing and examination and sampling of the iron are discussed.

Inductive Grey Cast Iron Melting. K. Grütter. (*Elektrowärme*, 1958, **16**, Aug., 267–274). The use of an induction furnace in a tube foundry is described, used duplexed with an electric low-blast furnace. Possibilities are dealt with and comparisons with other systems are made.

Inductive Melting of Steel at Mains Frequency. D. Hartmann. (*Elektrowärme*, 1958, **16**, Aug., 279–283). The use of the crucible type furnace for remelting is described for alloyed and non-alloyed steel casting. Melting losses are shown to be no greater than with medium-frequency furnaces.

Low Frequency Induction Furnaces. W. Von Asten. (*Engineer Foundryman* 1958, **22**, Feb., 35–37). Low-frequency induction melting is claimed to produce high quality irons from inferior materials. The principles and practical details of this type of furnace are described.—A. G.

Economical Considerations on the Inductive Melting of Iron and Steel. K. H. Brockmeier and W. Lang. (*Giesserei*, 1958, **45**, Aug. 14, 465–469). The authors discuss the principles and applications of low- and medium-frequency inductive melting of iron and steel and list the various factors involved in evaluating fixed and operational costs. Their discussions are supported by many graphs. A generally applicable conclusion on the most economic and best suited induction furnace cannot be given, as this depends on too many factors.—T. G.

Study of High Strength Cast Iron. (Report II). I. Iitaka and K. Nakamura. (*Waseda Univ. Rep. Casting Res. Lab.*, 1957 (8), 1–4). Trials are described in which oxygen is blown into liquid iron to reduce the amount of Si and C, instead of using steel scrap. The relation between supply of oxygen and the oxidation of Si and C, and the effect of adding inoculants are discussed.

Mechanical Properties of Cast Iron Produced by Liquid Pressing. G. K. Gedevanishvili and R. B. Zvernitskaya. (*Lit. Proizv.*, 1958, (3), 10–11). The findings of the investigation show that the crystallization of cast iron under pressure gives an appreciable increase in its mechanical properties after heat treatment as well as in the cast condition.—L. H.

New Acid-Resisting High-Strength Cast Iron. Z. B. Shapiro. (*Lit. Proizv.*, 1958, (5), 24–26). An investigation is described in which acid-resisting irons with spheroidal graphite were produced and their micro-structures and mechanical and corrosion-resistant properties were studied. Iron (2·6–2·9%C, 2·2–2·5% Si, 1·4–1·7%Mn, 0·8–1·1%Cr, 16–18%Ni, 3·0–3·5%Cu, up to 0·10 and 0·02%P and S, respectively) was melted and inoculated with Mg–Ni alloy. It was found that above about 4%Cu, spheroidization was difficult to achieve and that Cr content was also important, and upper limits for these of 4 and 1·1% respectively were fixed, the comparatively low Cu content being compensated by raising the Ni content to 16–18%. The properties of the metal finally chosen are compared with those of other irons and steels.—S. K.

Spheroidizing Capacity of Metallic Additions to Spheroidal Graphite Cast Iron. T. Kusakawa. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 9–12). Experiments are described in which the spheroidizing effects of additions of Ca, Mg and misch-metal are compared, tube experiments being carried out with the iron in the plastic state, at 1160° C.

The Influence of Alloying with Manganese, Chromium and Nickel on the Mechanical Properties of Spheroidal Cast Iron. Č. Hloušek. (*Slévárenství*, 1958, **6**, (6), 41–50). [In Czech]. The effect of the content of alloying elements, mainly Ni, Cr, and Mn on the microstructure, tensile strength, ductility, impact strength and hardness of low-alloy Mn, Cr and Ni spheroidal cast irons, on medium alloy Mn spheroidal cast irons, and on Cr–Mn and other high-alloy spheroidal cast irons was studied. Optimum alloy contents and the effect of heat treatment on the mechanical properties are also discussed.—P. F.

Improved Method of Inoculating Cast Iron With Magnesium in the Forehearth. I. P. Petrov. (*Lit. Proizv.*, 1958, (5), 12–13). The practice developed at the Syzranskiy heavy engineering works for introducing Mg into the metal in the cupola forehearth is briefly described. The Mg is now introduced in granular form in a container so that vaporization occurs gradually. A pipe is provided for removing excess fumes.—S. K.

Precision Steel Castings. (*Mech. World*, 1958, **138**, Aug., 356–357). Shell moulding, the Osborn–Shaw gelling refractory slurry process and the CO_2 block process as used by Osborn Precision Castings Ltd., a subsidiary of Samuel Osborn and Co., near Sheffield are described.

Low Silicon Castings and Pig Iron for the Manufacture of High Quality Steel Castings. N. A. Barinov. (*Lit. Proizv.*, 1958, (4), 7). Results are given of four experimental melts of different chemical compositions with tabulated results.—L. H.

Heavy Steel Castings Made by Pouring into Green Moulds made of Synthetic Sands. J. Fiala. (*Slévárenství*, 1958, **6**, (6), 186–193). [In Czech]. The technology of the process, its advantages and weak points are discussed, primarily by reference to two examples, i.e. a casting of 5·5 and one of 25 t weight cast by this method in the Lenin Works in Pilsen.

Sieve Ratios and Processing for Strong Molding Sands. J. Parisi, O. C. Nutter and C. Michalowski. (*Mod. Castings*, 1958, **33**, June, 82–87). A method is presented for relating the proportions of screen sizes for formulating moulding sands. Optimum techniques for the mixing and mulling of sand are described.—A. G.

Method for the Determination of Clay Content in Foundry Sand. J. Kashima.

(*Waseda Unie. Rep. Castings Res. Lab.*, 1957, (8), 27–31). It is pointed out that the method of determining clay content by measuring the transmittency of adsorbed organic dyes is unsatisfactory for bentonites. Nickel sulphate, N/10 in sulphuric acid, was found to give satisfactory results, and the experimental results obtained are described.

Industrial Applications of Olivine. G. S. Schaller and W. A. Snyder. (*Mod. Castings*, 1958, **33**, June 99–104). Compared with silica, olivine offers a slightly greater cooling effect, increased heat capacity, uniform thermal expansion, a slightly higher fusion point and controlled grain size. Investigations in a number of foundries are suggesting many profitable applications.—A. G.

Basic Principles of Patternmaking. J. A. de Kiewiet. (*Engineer Foundryman*, 1958, **23**, Feb., 87–92). A simple description of pattern-making is given aimed at apprentices for the foundry industry.—A. G.

Dimensioning of Risers. W. Koppe. (*Giesserei*, 1958, **45**, Aug. 14, 469–474). Equations for the calculation of risers are derived, particularly for grey cast iron, taking into account the expansion due to the precipitation of eutectic graphite, and the calculation of risers using diagrams as an aid is shown on some examples. The calculation of the gates is also dealt with.—T. G.

Some Problems in the Construction and Design of Runner-System Slag Traps. A. V. Kazantsev. (*Lit. Proizv.*, 1958, (5), 9–12). This is a theoretical and laboratory treatment, with some practical examples, of slag traps, with special reference to iron and steel castings. Assuming that the high viscosity of thickened slags makes the behaviour of their inclusions like that of solid particles, laboratory model experiments gave an approximate relation between the hydraulic and mechanical dimensions of inclusions. From an analysis of the particle movements the required trap dimensions to separate the slag are deduced and these are further examined to ensure that the separated slag is not re-entrained. Some proposed and actual trap designs and locations are discussed.—S. K.

Some Theoretical Problems on the Operation of a Sand-Slinger Rotor. R. L. Geller. (*Lit. Proizv.*, 1958, (5), 13–17). This is a theoretical discussion leading to the determination of the geometrical form of a packet of mould mixture in the rotor, the distribution of packing and pressure over the profile of the packet and the power required to overcome the friction between the packet and the guide.—S. K.

Mould and Core Mixtures Containing Bitumen. V. Otáhal. (*Slévárenství*, 1958, **6**, (6), 177–185). [In Czech]. Experiences with the use of bitumen in moulding mixtures used in a grey cast-iron foundry in Czechoslovakia are described. Bitumen additions were found to lead to a considerable reduction in the drying time of medium size moulds, in the consumption of sand, the reject rate, and the time of circulation of mould boxes.—P. P.

The Study of Organic Binders for Moulding Sand. J. Kashima and H. Suzuki. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 33–37). A number of driers were investigated for the purpose of accelerating the hardening of oil-bonded core sand. Cobalt naphthenate was found to give the most satisfactory results, at hardening temperatures of 100, 150 and 200° C.

Technological Factors Concerning the Durability of Moulds. V. M. Pishchev. (*Lit. Proizv.*, 1958, (3), 7). The conditions of working in relation to the dimensions have been considered and it has been found that, in order to increase the life of these moulds, it is advisable to shorten the distance to the point of pouring the metal into the funnel to 120–170 mm instead of the usual distance of 420–520 mm; to paint the moulds so as to provide them with a thin insulated working surface, and to arrange the operation in such a way that the tempreature of the moulds should not exceed 550°.—L. H.

Carbon Dioxide Cores in a Malleable Foundry. G. Nestor. (*Mod. Castings* 1958, **33**, June, 56–60). An account is given of experimental work to establish the conditions under which a wet sodium silicate-sand mixture can be treated with CO_2 gas to make cores of low hardness and gas content and good collapsibility. The final process resulted in a 20% saving over the core-oil sand process.—A. G.

Sintered Alumina Molds for Investment Casting of Steels. F. C. Quigley and B. Bovarnick. (*Mod. Castings*, 1958, **33**, June, 51–55). Molds are formed by dipping a wax pattern in a stable slurry of alumina and sprinkling with coarse alumina, repeating the process to give the desired thickness. The method is rapid and has produced high quality castings of several alloy steels.—A. G.

Precision Casting uses Mercury Patterns. (*Metalw. Prod.*, 1958, **102**, Aug. 22, 1472–1476). An account of the Mercast process as worked by Sankey-Telcon Ltd., Crawley, Sussex.

Moulding Castings for Rolling Stock. J. G. H. Loubser. (*Engineer Foundryman*, 1958, **23**, Feb., 99–107). Railway foundries have to produce bronze, iron and steel castings in large numbers. The organization and scope of casting production in South African railway foundries with special reference to the modernization of moulding methods and related equipment is described.—A. G.

Casting Radiators by the Surface Crystallisation Method. V. N. Bekhalov. (*Lit. Proizv.*, 1958, (5), 2–4). The work of the NIIST organization on the development of equipment for the surface-crystallization casting of radiators and some results obtained with an experimental plant at the Stolbovsk iron foundry are described. In this method the coreless mould is filled with metal which is tipped out after sufficient time has elapsed for crystallization near the mould surface to have occurred. The mould is attached to the outside peripheral surface and connected to the inside of a drum containing liquid metal: the mould is filled and tipped by appropriate rotation of the drum. Data on radiator wall thickness in relation to the type of gating used, the metal temperature, crystallization time and radiator dimensions are given. The micro-structure and performance of radiators cast by the new method and the casting equipment and its control are considered.—S. K.

Specifications for The Provision of a Compressed Air Installation in a Foundry. P. G. Lanino. (*Fonderia*, 1957, **6**, Nov., 481–484). [In Italian]. The article gives data on the uses of compressed air in foundry work and specifies quantities and pressures.

The Importance of the Quality of Fuel in the Utilisation of Reserves in Foundries. L. M. Marienbakh. (*Lit. Proizv.*, 1955, (9), 7–9. [In Russian]. In addition to details relating to various kinds of fuel, the desirability of the use of O_2 is pointed out.—L. H.

Influence of Blast Input, Coke Size and Melting Coke Ratios on Cupola Performance. F. Danis and M. Decrop. (*Found. Trade J.*, 1958, **104**, Mar. 20, 319–325; Mar. 27, 351–358). A cupola 28 in. dia. with lining 10 in. thick was used and charge, blast, temperature, and gases were carefully determined and thermal balances worked out. Temperature zones were explored and an extensive analysis of the results is presented.

Maximum and Minimum Coke Consumption in Cupolas. G. Balaban. (*Met. Constr. Masini*, 1957, **9**, (7), 9–13). [In Rumanian]. The determination of coke consumption was made in a cupola with forehearth and three rows of tuyeres. The minimum limit was fixed when the melting zone was just below the oxidising zone. A reduction of coke below this minimum may lead to "freezing." The maximum limit is determined by the minimum quantity of coke necessary to obtain the highest temperature of the liquid iron. Any increase beyond this quantity is uneconomic and reduces production.—L. H.

Experiences with Water Cooled Cupolas. N. A. Barinov. (*Lit. Proizv.*, 1955, (9), 9–12). [In Russian]. In a water cooled cupola built in 1951 and designed to work 16/18 h of the 24, it was found that the water jacket does not protect the linings, which at the level of the melt, were burnt away after 8/10 h production, with formation of a crust of 10 to 15 mm of slag and hardened iron droplets. After the formation of this crust, the melt continued without lining. Various other systems of water cooling are described and examined and records are given of cupola production under practical conditions.—L. H.

Production of High Quality Iron from the Cupola. I. B. Khazan. (*Lit. Proizv.*, 1955, (11), 4–7). [In Russian]. A diagram is given of a proposed arrangement of the hearth of the cupola and a scheme for the process is recommended for the production of low-sulphur, degassed, high-quality iron freed from slag. For this purpose a combination is recommended of a cupola with forehearth. The bottom built on one level sloping at an angle between 5 and 10°. In this way the furnace and forehearth are always connected and completely clear of slag. The iron in the additions is heated to 1450° by the combustion of natural gas.—L. H.

The Change in Chemical Constitution and in Temperature of the Metal, in Blowing Iron with Oxygen in the Forehearth of Cupolas. N. A. Voronova and O. A. Trigub. (*Lit. Proizv.*, 1955, (7), 17–20). [In Russian]. Experiments undertaken in various foundries are set out showing the changes in chemical composition and temperature, on O_2 blowing in comparison with the normal operations of cupolas, and some conclusions are drawn from the results.—L. H.

Experiences with Basic Cupola Refractories and Melting. E. Boywid and A. P. Alexander. (*Trans. A.F.S.*, 1956, **64**, 493–503). A number of constructions and refractories were used and slag and metal, coke ratio, and cost comparisons are given for a gradual change over from acid to all-basic construction.

Properties of Refractories Affect Air Furnace Bottom Service. C. C. Lawson and L. R. Jenkins. (*Trans. A.F.S.*, 1956, **64**, 432–434). Eight refractories were compared in two furnaces forming part of a duplexing system with cupolas, fired by pulverized coal. Failure originally occurred by joint penetration. Alumina bricks are regarded as most satisfactory.

Recent Development of the Coreless Line Frequency Induction Melting Furnace in European Foundries. O. Junker. (*Trans. A.F.S.*, 1956, **64**, 543–550). Non-ferrous uses and the melting of spheroidal graphite iron are reviewed and the recent extension to steel melting. Types of furnace are described and operating data given.

Induction Melting Steel at Mains Frequency. (*Engineering*, 1958, **185**, Apr. 4, 421). The furnace of the Inca Steel Co., Sheffield, is briefly described.

Induction Melting Furnaces with Mains Frequency. V. S. Astaulov. (*Lit. Proizv.*, 1957, (12), 5–8). Based on the theoretical aspect of induction heating at mains frequency, suggestions are made for the construction of suitable furnaces with proper dimensions for industrial production.—L. H.

The Use of Low-Frequency Induction Furnaces in Iron and Steel Foundries. A. Tagliaferri and P. L. Oliva. (*Fonderia Ital.*, 1957, **6**, Dec., 469–476). [In Italian]. The article describes certain recent developments in the design and construction of electric induction furnaces. Data on refractory linings and power consumption for furnaces of different sizes are given.—M. D. J. B.

Automotive Grey Cast Iron. D. L. Watson. (*Can. Metalw.*, 1957, **20**, Nov., 42, 44–46; Dec., 42, 44, 46; 1958, **21**, Jan., 54, 56). Engine block production is described. The constitution, hardness, effect of Cr, and shrinkage cavities, casting zones, elements influencing graphite formation, and the effects of P are reviewed. Solidification, chill, transformations, effect of fluidity and carbon pick-up, control of Si, effects of limestone ratio and ideal conditions are considered. Cupola practice is outlined with practical hints.

Use of Pig Iron in Iron Foundries. With Particular Attention to Specifications, Prices, Secondary Elements, and "Heredity." H. W. Lownie jun. (*Trans. A.F.S.*, 1956, **64**, 104–124). A review of specification and methods of production, AISI and ASTM classifications, method of analysis and uses of different grades is given. Prices since 1930

are shown. Effects of S, P, Mn, Si, C, and a list of other elements detected are noted. Nodular and malleable castings are then considered and "heredity," the tendency for the microstructure of the pig iron to be repeated in the castings, is discussed.

Cast Iron with Nodular Graphite. (*Verein Deutscher Giessereifachleute, Düsseldorf*, 1955, pp. 74). A bibliography with brief abstracts.

Study on Production of Spheroidal Graphite Cast Iron by Calcium Treatment. Y. Horiuchi. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 905–908). Comparative results are given for effects on various irons (analyses given) of treatment by CaSi, metallic Ca, CaC_2 and Ca-Cu alloy in varying amounts; they include the mechanical properties and the amounts of spheroidal graphite. (14 references).—K. E. J.

The Effects of Ladle Additions and Ladle Vibrations on the Mechanical Properties of Ferritic Nodular Cast Iron. I. Pavlik. (*Slévárenství*, 1958, **6**, (1), 9–14 supplement). [In Czech]. The influence of various ladle additions and ladle vibrations on the quality of nodular cast irons is surveyed, and the author's own work with Al, B, FeTi and FeSiCa additions to white cast irons is described. Boron (0·001–0·005%) decreases the tensile strength, and in the range 0·002–0·005% increases the elongation. Similar effects arise with Al, the corresponding concentration ranges being 0·005–0·2% and 0·01–0·05% respectively. Both tensile strength and elongation are increased by additions of up to 0·2%FeTi with up to 0·2% FeSiCa. Vibrations were virtually ineffective.

The Use of Tellurium in the Iron Foundry. (*Fonderia*, 1957, **6**, Dec., 529–530). [In Italian]. The effect of using Te in iron castings is discussed briefly. It is shown that Te has a strongly stabilizing action on the carbon and that it can be used to harden parts of a casting.—M. D. J. B.

Influence of Slag on the Properties of Manganese Cast Iron. B. K. Ivanov and T. G. Ivanova. (*Lit. Proizv.*, 1955, (10), 28–29). [In Russian]. In substance, the findings show that for the manufacture of Mn iron with spheroidal graphite, and with the essential mechanical properties, slag must be completely eliminated from the surface of the metal, by treatment with Mn. Afterwards the cast iron in the ladle is again cleared by a sprinkling of dry sand, so as to produce a crust of the remaining slag.—L. H.

Spheroidal Graphite Iron in Steam Fittings Production. M. Pachowski. (*Prz. Odlew.*, 1957, **7**, June, 166–169). [In Polish]. Applications of different kind of fittings made from spheroidal graphite iron are described. They show satisfactory results and confirm the suitability of this material for fittings working under conditions of high water and steam pressure.

Side Valves and Saddles in S.G. Iron. (*Inco-Mond Mag.*, [1958], (5), 32–33). Side valves for ships and saddles carrying deck steam lines are made of nodular graphite iron.

Piston Rings from Spheroidal Cast Irons. J. Musil. (*Strojírenství*, 1957, **7**, (12), 914–916). [In Czech]. Laboratory and works experiments on the suitability of inoculated cast irons for the manufacture of piston rings are reported. Such rings can replace Cr plated grey cast-iron or steel rings in all cases.

Castable Ductile Metal for Strong, Complex Parts. J. Schuyten. (*Western Metalw.*, 1958, **16**, Feb., 23–26). An account of a new nodular iron known as Spherulite, and its properties and uses.

From Industrial Experience. A. P. Shakhov and S. S. Krasnovskii. (*Lit. Proizv.*, 1955, (11), 25–27). [In Russian]. This study shows the possibility of developing technology for the manufacture of castings of malleable iron from charges of iron for steel manufacture. The technological process of introducing iron for steel-making into the charge has proved itself very flexible and favourable to production. It gives the opportunity of regulating the silicon content between the limits of 0·9 and 1·4%.—L. H.

Mechanised Malleable Foundry. African Malleable Foundries. (*Eng. Found.*, 1958, **22**, Jan., 35–36). An account of the system at the Benoni works.

The Influence of the Melting Process in the Cupola on the Quality of Malleable Cast Iron. B. Sochor. (*Slévárenství*, 1958, **6**, (1), 1–8 (Appendix)). [In Czech]. The effect of slag composition on the mechanical properties and structure of malleable cast iron produced in an acid cupola was studied. Small additions of sodium carbonate and of borates led to an increase in the fluidity of the slag. Additions of up to 1% of the weight of the metal charge of soda resulted in improvements of the mechanical properties of the iron, while borates caused a small deterioration. Boron entered the metal from the slag in amounts giving concentrations of thousandths to tenths of a per cent, and influenced the structure appreciably. If present in extremely small quantities, boron has a beneficial effect on the decomposition of cementite, thus shortening the malleablizing cycle. The use of a pre-heated blast, employed in some runs, was found to lead to better desulphurization, lower carburization and better degassing, i.e. it had a desirable effect on the quality of the metal and resulted in a more even running of the cupola.—F. F.

Influence of Oxygen Blowing on the Mechanical Properties of Malleable Cast Iron. M. M. Turbovskii. (*Lit. Proizv.*, 1955, (10), 23–25). [In Russian]. For the study of the influence which O_2 blown into the forehearth of the cupola, has on the mechanical properties of the product, data have been collected over two years concerning the chemical composition and the mechanical properties of malleable cast iron obtained in the normal way by melting in cupolas, and by O_2 blowing. Yearly averages for white cast iron, show that the chemical composition hardly varies between the two methods. It follows therefore that the differences in the physico-chemical processes in connection with the blowing of O_2 on to the metal (overheating, oxidation of metal, and the facilitation of inoculation), exercise an appreciable influence on the improvement of the mechanical properties of malleable cast iron.—L. H.

Production of Malleable Cast Iron in West Germany. W. Sakwa. (*Prz. Odlew.*, 1957, **7**, July, 192–195). [In Polish]. General characteristic of German foundries, the organization of work, mechanization, and the construction of annealing furnaces are described.

On the Antifriction Theory of Malleable Cast Iron. Ya. G. Lifshits. (*Lit. Proizv.*, 1955, (10), 22–23). [In Russian]. Malleable cast iron with inclusions of free structural cementite in a ferrite or pearlite matrix has not proved itself as an antifriction material which could be used as a bearing metal. The grains of the very hard cementite, on which the rotating shaft rests, resist the running in, and wear out the shaft by acting abrasively.

Comments on the Article "The Technology of Melting Malleable Iron and Its Future in the Rumanian Popular Republic by A. Ludovic." Gh. Belei. (*Met. Constr. Masini*, 1957, **9**, (10), 14–15). [In Rumanian]. This is a reply to the article which appeared in the same periodical (12) 1956. The author does not agree that the simplex process is justified under to-day's conditions.—L. H.

Gravity Die-Casting of Radiators. A. M. Osokin. (*Lit. Proizv.*, 1958, (5), 4–5). To avoid difficulties in the gravity die-casting of radiators, the NIIST organization has produced radiator designs specially suited to this method. These and the casting procedures used are briefly described in this article.—S. K.

Cast Iron Spun Pipe Plant at Bhadravati. (*Iron Steel Rev.*, 1958, **1**, May, 31–32). An account of the opening of the Mysore plant.

Mathematical-Statistical Investigation of the Service Life of Centrifugal Casting Moulds as a Function of Casting Frequency. H. Bühler and W. Schreiber. (*Giesserei Techn.-wiss. Beihefte*, 1958, (**21**), July, 1137–1139). The conclusions drawn by the authors (*ibid.*, 1957, July, 889) were disputed in a letter by R. Schaeffer, who claimed that optimum values of the casting frequency cannot be derived from the data the authors provided. The authors reply.—T. G.

Gas Pressure in the Mould Cavity. (Rept. II). M. Mutaguchi. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 39–42). Experiments carried out to investigate the relation between gas pressure in the mould cavity (p) and mould permeability (P) showed that $p^n \propto 1/P$.

Effects of Several Moulding Materials on Sand Adherence to Steel Casts. S. Minowa. (*Rep. Gov. Ind. Res. Inst.*, 1958, **7**, June, 406–411). [In Japanese]. Steel buried in sand, bentonite, zircon sand, iron oxide, chromium oxide or lead oxide was melted by induction, cooled to room temperature, and the adhesion noted. The product of interaction with sand was identified as fayalite.

Some Factors Influencing the Formation of Heat Cracks in Steel Castings. A. M. Lyass and Chzhou-Yao-Kho. (*Lit. Proizv.*, 1958, (3) 20–24). The experimental findings have shown that between 1410 and 1385° the yield point lies between 0·075–0·215 kg/mm² and the elongation between 0·23 and 0·44%. Experimental data for a range of temperatures have served for the construction of curves for yield-point and plasticity for carbon steels at high temperature. In this way, the influence of various factors such as grain structure, temperature and rate of deformation has been investigated.—L. H.

Shaking-Out Grid for Heavy Castings. G. Z. Lipovetskii and I. P. Burtsev. (*Lit. Proizv.*, 1958, (3), 14–16). Descriptions, drawings and dimensions are supplied of a few grids, the use of which has proved satisfactory.—L. H.

Economic Accuracy of the Weight of Castings. M. G. Shtanko. (*Lit. Proizv.*, 1958, (5), 6–9). The author outlines the errors and difficulties involved in determining the accurate weight of various types of casting, analyses the reasons for the errors and gives tabulations of extensive data. These enable the qualitative and quantitative effects of technological factors on the weights of real castings to be found and the rules of weight distribution of parts within a batch for normal production conditions and the weight accuracy to be calculated. He shows that the differences between the arithmetic mean and the design weights range from −6·5 to 39·5%, the range of scatter of weights of casting within a batch being from ± 3·3 to ± 12·15%.

The Calculation of Bridges for Heavy Foundry Cranes. I. M. Odin. (*Vestnik Mashin.*, 1958, (7), 20–23). The method of calculating heavy foundry cranes of 175–350 t lifting capacity, by considering the frame separately for each component girder gives values with wide approximation. Here a mathematical method is proposed for a calculation based on taking the frame and the load as symmetrically placed along the longitudinal axis of the bridge so that for calculation purposes only half the arrangement need be considered. The formulæ so obtained give accurate results.—L. H.

Noise and Noise Suppression in Foundries. H. Berndt. (*Giesserei Techn.-wiss. Beihefte*, 1958, July, 1141–1146). The author discusses the sources of noise in a foundry and its effects on the men. A number of recommendations for the suppression of noise from equipment and buildings are made. The use of sound-insulated boxes around machinery is recommended even if the output of the machine is thereby reduced.—T. G.

VACUUM METALLURGY

Vacuum Melting of Steels. H. C. Child, G. T. Harris. (*J.I.S.I.*, 1958, **190**, Dec., 415–431). (This issue).

Vacuum Casting of Steel. J. N. Hornak and M. A. Orehoski. (*J. Metals*, 1958, **10**, July, 471–475). A vacuum-casting process is described which has been developed for the manufacture of steel for large forging sections, to give a maximum hydrogen content of 1·5 p.p.m. The tensile ductility of the aged and unaged steel is approximately the same.

Vacuum-Flow Steel Degassing. F. W. Starratt. (*J Metals*, 1958, **10**, July, 465).

The process described is at present in the development stage at the Ruhr steel plant of Heinrichshütte, and appears to be an effective, low-cost technique for producing low-hydrogen forgings and castings. The steel, held in an ordinary 60–80 ton steel ladle, is treated by immersing in the liquid two tubes connected to a chamber evacuated to 0·1 mm Hg. Argon is blown through one tube, metal rising up this tube and re-entering the ladle through the other. De-gasification is completed in 12–15 min. and is continued until the analysis of gas taken from the pump is satisfactory.

Vacuum Pouring of Ingots for Heavy Forgings. J. H. Stoll. (*A.I.S.I. Preprint*, 1958, pp. 31). The author discusses the Bethlehem Steel Co.'s experience in the vacuum pouring of steel ingots. Details are given of the 7-t development unit and the present 250-t units, and their operation is outlined. The effects of the treatment on H_2 removal, mechanical properties, cleanliness, and flaking susceptibility are described, and cost factors are considered. Finally, the possible future potentialities of the process are discussed.—G. F.

Methods and Effects of Vacuum Casting Steel. L. R. Cooper. (*A.I.M.E.E., Proc. O.H. Comm.*, 1956, **39**, 131–140). The author reviews work on vacuum casting carried out at Bochumer Verein A.G. and describes the three main processes of ladle de-gassing, stream droplet de-gassing, and vacuum ingot casting. Typical analyses are quoted showing the reduction in O_2, N_2 and H_2, and metal oxide contents in each process, and the important reduction in flaking tendencies is emphasized.—G. F.

REHEATING FURNACES AND SOAKING PITS

Automatic Control of a New Continuous Bloom Reheating Furnace. (*Brit. Steel.*, 1958, **24**, July, 218–219). A new Priest bloom reheating furnace at South Durham Steel & Iron Co. Ltd. is fully instrumented and equipped for automatic control by Electrofio Meters Co. Ltd. Details of the system are given.—G. F.

Automatic Control of Continuous Bloom Re-heating Furnace. (*Iron Coal Trade Rev.*, 1958, **176**, June 27, 1556–1557). The system at the Cargo Fleet ironworks is described.

Inductive Heating of Steel for Forging. H. Hammersen. (*Elektrowärme*, 1958, **16**, Aug., 289–295). Advantages of the method, such as uniformity of heating, are described.

Induction Heating for Forging. P. E. Hammarlund and Y. Sundberg. (*Met. Treatment*, 1958, **25**, June, 249–253). The theory is outlined with reference to choice of frequency, power requirements and heater design. Advantages and disadvantages are set out.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Liquid Metal and Salt Baths. A. D. Hopkins. (*Met. Treatment.*, 1958, **25**, May, 197–204). A review of lead, cyanide, neutral salt, nitriding and sulfinuz baths is given and advantages are summarized.

Salt Baths and Salt Bath Furnaces. H. Solakian. (*Met. Treating*, 1958, **9**, Mar.-Apr., 8–9, 38, 39, 52, 53). The intermediate (1200–1800° F) and high temperature ranges (1850–2350° F) are surveyed.

Graphite Resistor Furnace: Efco Unit at Lake & Elliot Ltd. (*Iron Steel*, 1958, **31**, Apr., 132). The new type of Efco graphite resistor furnace installed at Lake & Elliot Ltd. has a body similar to an electric-arc furnace, facilitating charging, fettling, and slag removal. Brief details are given of the furnace refractories, electrical gear, and furnace operation.—G. F.

Temperature Uniformity in Heat Treating Furnace. F. C. T. Daniels and S. Stasko. (*Ind. Heat.*, 1958, **25**, July, 1342, 1344, 1346). A process using a small excess of air is described.

Simple, Gas-Tight Furnace for Induction Heating. R. D. Grinthal. (*Powder Met. Bull.*, 1958, **8**, June, 68–69). A quartz tube furnace 2½ in. dia. × 24 in. long, with a uniform heat zone 4 in. long and 1½ in. dia. attaining 1900° C is described.

A Theory for Preheating of Plain Low-Carbon Steels. E. P. Degarmo. (*Weld. J.*, 1958, **37**, March, 93-s–96-s). The improved performance following pre-heating is attributed to the reduction of micro-cracking due to the elimination of retained austenite. On the basis of this theory conditions under which preheating will improve performance are indicated.—A. G.

Induction Heating for Shrink-fitting. D. W. Thomas. (*Machinery*, 1958, **93**, Aug. 20, 441–442). A process used by the G.E.C. (U.S.A.) is described.

Heat Treatment of Missiles and Aircraft Components in Flexible Installation. (*Ind. Heat.*, 1958, **25**, July, 1349–1350, 1352, 1354). A controlled atmosphere installation at Fort Worth is described.

Steel Heat Treatment Quality Control. I. The Quality Control Plan. K. Kornfeld. (*Can. Metalw.*, 1958, **21**, Mar., 24, 26, 28). A discussion in general terms of the controls necessary.

Influence of Cold and Hot Treatment on the Durability of Crankshafts. Z. Müller. (*Met. Constr. Masini*, 1958, (3), 197–204). [In Rumanian]. Broken crankshafts have lately occurred more frequently both in imported motors and in motors from home production. Hence this rather detailed study of possible causes of failure and of the tests deemed necessary.—L. H.

The Heat Treatment of En Steels. F. C. Bird and G. R. Morton. (*Met. Treatment*, 1958, **25**, June, 239–248). Descriptions and diagrams are given for the members of the En range of steels.

Combination Gas and Electric Heating in Rotary Hearth Furnace for Treating High Speed Steel Bearing Rings. (*Ind. Heat.*, 1958, **25**, March, 496–498). Steel bearing rings require a preheat at 1400–1700° F followed by heating at 2000–2400° F. These two operations are effected in a rotary hearth furnace using gas for the low temperature zone and electric resistance heating for the high temperature region.—A. G.

Controlled Atmospheres for Metallurgical Processes: Part I. I. L. S. Golding. (*Met. Treatment*, 1958, **25**, June, 221–226). Case hardening, carbo-nitriding, annealing, billet heating and tempering are briefly reviewed.

Improved Equipment, Material Standards, Inspection Needed for Metal Treating. G. Berlien. (*Western Metalw.*, 1958, **16**, Apr., 60–61). A general account of directions for improvement is given.

Jigs and Fixtures for Heat Treatment. L. G. H. Palethorpe. (*Met. Treatment*, 1958, **25**, July, 275–282). Designs for use in furnaces, for quenching and for induction heating are reviewed.

Effect of Ti, V, W and Zr on the Resistance to Sulphurization of Cast Iron at High Temperatures. M. Shiozawa and H. Nakai. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 13–15). Allowing additions of Ti, V, W and Zr were all found to increase the resistance of iron to sulphurization, as measured by increase in weight in a current of H_2S at 900° C. The mechanism of this effect is discussed.

Solid Solution Hardening. W. R. Hibbard jun. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 1–5). The author presents evidence which indicates that models of solution strengthening, depending solely on lattice parameter changes, are incomplete. Direct evidence for the Suzuki interaction of chemical effects was obtained from alloys with constant lattice parameters, for which solution strengthening was nearly independent of temperature from 300° to 20° K.—G. F.

Case Hardening "Hardened" Rods. A. Luksch and P. B. Wallace. (*Met. Treating*, 1958, **9**, Mar.-Apr., 6–7). Treatment in two stages of a heavy duty scarifying tool is described. Cold-drawn SAE 4150 bar is surface hardened by induction after conventional heat treatment.

On the Free Carbon Deposition during Converting of Carburizing Gases. A. Adachi. (*Osaka. Univ. Fac. Eng. Techn. Rep.*, 1957, **7**, Oct., 379–384). Conversion of impure propane–air mixture produced more carbon than CH_4–air or pure C_3H_8–air mixtures. The composition of the gas and trials with propylene and other constituents are reported.

Induction Hardening Heavy Tractor Axles at Oliver Corporation. (*Ind. Heat.*, 1958, **25**, March, 518). Brief details are given of a new automatic induction axle hardening machine at the Oliver Corporation works, Iowa, capable of treating 260–300 axles per 16 h day.—A. G.

Deformation of Steel with Induction Heating. G. V. Klyushin. (*Metallov. Obra. Met.*, 1947, (1), 59–64). It is well known that under the influence of heat stresses, a solid body tends towards a spherical shape, thus in tall cylinders, the diameter increases and the height decreases and in wide cylinders vice-versa. This fact is the subject of the present enquiry on specially prepared specimens and on objects such as roller axles, crankshafts, grooved spindles, etc. The tests were carried out on a 150 kW apparatus at 2000 cycles and the distance between specimen and electrodes kept constant at $3 \pm 0{\cdot}5$ mm with cooling in air and annealing before induction heating. It was established that when the ratio of the height of the complex object to its radius was greater than 1·32 the cross-section dimensions increase against a decrease in length and when this ratio is smaller the opposite effect is noticed. Microstructure, mechanical properties etc. have been investigated in this connection and the findings are set out in detail.—L. H.

Nitriding of the Special Steel Cr–Mo–V. Z. Rigani. (*Met. Constr. Masini*, 1958, (4), 291–296). [In Rumanian]. This study extends to the thermal treatment, to the nitriding process and to the conditions for obtaining maximum hardness of the nitrided layer, its maximum depth, the optimum plasticity of the core after nitriding and a minimum of deformation. The experiments are described.

Annealing Cycles for Commercial and Drawing Quality Rimmed Steels. H. E. Miller. (*Ind. Heat.*, 1958, **25**, July, 1369–1370, 1372, 1374, 1376). Structures are shown.

Opened Coil Annealing With Recuperative Heating Increases Production Capacity. (*Ind. Heat.*, 1958, **25**, May, 949–960). The various stages in the open coiled annealing process are described. Technical and economic advantages are considered.—A. G.

Stress Relieving of Stainless Steels and the Associated Metallurgy. R. A. Huseby. (*Welding, J.*, 1958, **37**, July, 304s–315s). The nature of residual stresses and their effects on the properties of martensitic, ferritic and austenitic stainless steels are discussed. The objects and mechanism of stress relief are dealt with for the various types of stainless steels.

Relief of Stresses in Quenched 1·2% Carbon Tool Steel U12A. A. A. Gol'denberg. (*Metallov. Obrabotka Met.*, 1958, (2), 6–11). Ring specimens were bent and annealed. The first period of stress relief of quenched plain carbon steel was found to be shortened if phase changes started by tempering are continued. Increase in initial stress speeds relaxation but not in a simple manner. The extent of stress relief depends on the structural stability of the steel and instability in some cases, outweighed the effect of higher temperature so that stresses may be relieved more rapidly at lower than at higher temperatures.

Toughening Parts Subject to Abrasion, Impact. E. L. Launder. (*Western Metalw.*, 1958, **16**, Apr., 62–63). A counterflow arrangement of a normalizing furnace, hardening unit and two draw furnaces for the hardening of excavating equipment teeth is described. The line is gas-fired and atmosphere controlled.

On the Deterioration of Quenching Oils. M. Tagaya and I. Tamura. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1957, **7**, Oct., 403–424). Tests on 14 oils were carried out and air-blowing was also used and changes in properties were followed. Organic oxidation inhibitors were also tested.

The Effect of Quenching from Rolling Temperatures on the Properties of Thick Steel Sheet of Strength 73–84 Tons/Sq. Inch. M. Žídek. (*Hutník*, 1958, **8**, (5), 151–159). [In Czech]. Sheet of guaranteed weldability, containing 0·2%C, max., 1·5%Mn, max., and 0·55%Si, max., up to 1·2 in. thick was water-quenched from the rolling temperature, the latter sometimes being below Ar_3. Such a rapid quench, preceding tempering, was found to increase the final tensile strength after tempering without loss of impact strength. Optimum tempering conditions are considered.

Isothermal Bright Quenching of Cold-Wound Springs of 0·60% C, 2% Si Steel 60 S2A. B. V. Venkov, I. I. Borisova and M. A. Noskova. (*Metallov. Obrabotka Met.*, 1958, (4), 44–45). Specimens heated in a salt bath to 850° C were transferred to a bath of 63%KOH–37%NaOH and quenched in water. Best results were obtained by isothermal quenching in a bath at 270° C for 20 min. Above this the springs showed permanent set. Less than 20 min did not decompose all the austenite and more had no effect. The structure obtained showed troostite and a little retained austenite.

Marquenching. (*Mech. World*, 1958, **138**, Aug., 349–350). Essentials of the process and its relation to martempering are discussed.

Distortion Reduced by Automatic Marquenching. (*Machinery*, 1958, **92**, June 20, 1472–1474). The process as worked by International Harvester Co. at Fort Wayne is described. Pusher furnaces using natural gas, and generated endothermic gas in the last stage, are employed. Quenching oil is maintained in a protective atmosphere and one batch has been used for 16,941 h.

Heat Treatment of Dies: Martempering Unit at Edward Pryor and Son. (*Iron Steel*, 1958, **31**, June, 327–330). Details are given of the layout and equipment of the new heat treatment shop of Edward Pryor & Son Ltd. Particular attention is given to the martempering unit, which comprises a twin pot "Cassel" gas-fired hardening furnace and a controlled heat quench tank fitted with agitator and salt separator basket.—G. F.

Process of Carbide Formation During the Tempering of Carbon Steel. B. A. Apaev. (*Metallov. Obra. Met.*, 1957, (1), 2–15). It is shown that all carbon steels can be divided into three groups according to the stability of the carbide phase formed on tempering: steels containing up to 0·4%C, 0·6–0·8%C and over 1%C. Each type is described.—R. S.

A Study of the Early Stages of Tempering in a 0·2%C, 9%Cr and 0·38%V Steel. A. K. Seal. (*Trans. Indian Inst. Met.*, 1958, **11**, June, 73–80). Isothermal tempering at 170° for up to 1000 h was carried out and hardness, optical and electron micrographs, and X-ray studies of carbide isolates and electron diffraction studies of replicas were made.

FORGING, STAMPING, DRAWING, AND PRESSING

Some Aspects of Drop Forging Practice. K. Fidler. (*Trans. Manchester Assoc. Eng.*, 1954–1955, 339–350, discussion 350–358). Types of hammers and presses are briefly reviewed and die design and the properties of the steel required are discussed.

2000-Ton Steel Forging Press Installations at Dunkirk, New York. (*Engineer*, 1958, **206**, Aug. 15, 274–277). A press handling 15 t ingots installed by Allegheny Ludlum is described.

Calculation for the Safety Device Protecting the Clamping Mechanism of Horisontal Forging Machines from Overloads. I. I. Girsh. (*Vestnik Mahin.*, 1958, (7), 52–56). Detailed explanations and formulae are given for calculating maximum stresses on the protecting devices. The limiting curves which have been drawn up can be used in operations for the cutting of upset forgings from bars, and for other light operations.—L. H.

Selection of Parameters for Elements Insulating Forge Hammer Foundations from Vibrations. V. F. Shcheglov. (*Vestnik Mashin.*, 1958, (7), 46–51). Vibro-insulation is considered from the point of view of suspension and of support in relation to the hammer. The mathematical basis of the parameters is worked out and formulae derived suitable for practical application.—L. H.

A 2000 t Hydraulic Forging Press. S. M. Nekhai. (*Vestnik Mashin.*, 1958, (7), 44–45). A description of the press type P 156 manufactured at the SKB Novosibirsk Works "Tyazhstankogidropress" (Heavy Machine and Hydraulic Presses).—L. H.

A Survey of Forging Manipulators and their Applications. P. L. Lillywhite. (*J.I.S.I.*, 1958, **190**, Dec., 395–413). (This issue).

The New Vauxhall Press Shop. (*Machinery*, 1958, **92**, June 20, 1432–1455). An illustrated account of the layout and equipment of the extensions at Luton. Besides details of the presses, handling and scrap disposal methods are given.

Deep-drawing Research. E. E. Michaelis. (*Sheet Met. Ind.*, 1958, **35**, June, 459). A letter. The Swift, Erichsen and other tests and their value and significance are briefly considered.

A Boron Steel for Deep Drawing. L. R. Shoenberger. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 402–405). Sufficient boron, with small amounts of Al as a protective deoxidizer, was added to the casting ladle to produce semi-killed ingots. Good ingot yields with satisfactory ingot surface quality were obtained. Non-ageing low-carbon steel strip was produced. The steel contained 0·006–0·012%B, strain ageing resulting from B contents less than 0·006%. Some unusual structures were found, associated with the presence of well dispersed iron boride.

Ingot Thickness As It Affects Drawing Quality. J. S. McNairn. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 142–146). The author describes a series of tests made to establish the effect, if any, of an increase in ingot thickness, from 22 in. to 26 in., on the drawing quality of the product. No significant effect was observed.—G. F.

Influence of Ingot Thickness on Deep-Drawing Steels. C. F. Schrader. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 166–170). The author gives details of analytical, physical, and mechanical tests carried out on sheets rolled from rimming ingots of identical composition and of thicknesses ranging from 22 in. to 28½ in. No significant differences are observed.—G. F.

New Drawing Process Eliminates Heat Treating for Strong Parts. E. S. Nachtman and E. B. Moore. (*J. Met.*, 1958, **10**, Apr., 281–284). The authors describe the development of elevated temperature drawing (200°–1200° F). The product has all the advantages of cold-drawn bar with two added features—appreciably higher strength, and more uniform structure and quality. This has permitted the replacement, for certain applications, of heat treated alloy steels by carbon steels drawn at elevated temperature.—G. F.

Drawing of Sheet Through a Rotating [Pair of] Rolls. H. Yamanouchi and I. Hayashi. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 63–66). The conditions are formulated and test-pieces with photographed grids were pulled through the rolls. The tensions approximated to fixed rolls with large reductions in thickness and small rolls and to the expression for rotating rolls with smaller reductions and larger rolls.

Improvement of a Method of Testing the susceptibility of Metals to Piercing. N. S. Kirvalidze and I. Yu Korobochkin. (*Zavods. Lab.*, 1958, (7), 850–854). The method of investigating heated high-alloy steels, for seamless tubing, consists of piercing a specimen with a varying diameter along its length and, from the data so obtained, determining under laboratory conditions the influence of the various factors such as quality of the metal, its chemical composition, etc. on the operation and selecting the optimum temperature. Owing to the simplicity of the method it is recommended as a standard for routine investigations.—L. H.

Variation in Wall Thickness of Seamless Tubes Drawn Without a Mandrel. O. Cuida. (*Studii si Cercetari de Metalurgie*, 1957, **2**, (4), 491–497). The variations occurring in the thickness of these cold-drawn tubes have been investigated as a function of the ratio of the external diameter to the wall thickness. A relation was derived which gives qualitative and quantitative indications sufficiently close for use in production.—L. H.

Materials Used, Heat Treatment and Output of Thread Rolling Tools for the Manufacture of Screws. H. Assmann and H. Buchhausen. (**Werkstatt und Betrieb*, 1949, **82**, Nov., 390–396; Dec., 435–440). It is shown that tool output capacity depends on design, quality, heat treatment and care as well as alloy composition.

New Works for Darwins Bright Steels Limited. (*Brit. Steel.*, 1958, **24**, July, 202–203). The new Kingfield Works of Darwins Bright Steels Ltd. houses all the wire-drawing activities of the Darwins Group under one roof. A brief account is given of the general layout of the new works.—G. F.

ROLLING MILL PRACTICE

Effect of Residual Stresses on Contact Ageing Properties of Cold Rolling Rolls. V. N. Novikov. (*Metallov. Obra. Met.*, 1957, (1), 43–50). The various groups of factors affecting the life of rolls in cold rolling mills are discussed. Tests were carried out on 10 in. rolls to ascertain the resistance of the hardened layer to fatigue cracking. The zone of residual stresses is much deeper than that of maximum shear stresses. The combination of these stresses exceeds the fatigue strength of the hardened layer and thus primary cracking is caused.—R. S.

Report on Steel, I. Expansion and Pioneering. Stelco Opens No. 2 Blooming Mill. (*Can. Metalw.*, 1958, **21**, Mar., 8–9). A mill to handle 30-t ingots convertible to a universal slabbing mill rolling slabs up to 72 in. × 28 ft has been opened. Details of soaking pits and safety arrangements are also noted.

Geleji's Formula for the Determination of Mean Roll-Pressures in Hot Rolling. L. Hellebrand. (*Hutn. Listy*, 1958, **13**, (4), 312–315). [In Czech]. Geleji's formula, given in his book published in Budapest in 1955, which is based on the maximum shear stress criterion, is shown to overestimate actual, experimentally determined roll pressures. A modified formula is proposed.—F. F.

Newcastle's New Skelp Mill. E. J. Buckman. (*B.H.P. Rev.*, 1958, **35**, Apr., 11–15). An illustrated account of the design, construction and equipment of the New South Wales plant.

New Plant at Shepcote Lane Rolling Mills. (*Brit. Steel.*, 1958, **24**, June, 182–185).

Hot Rolling Stainless Steel Strip. (*Iron Steel*, 1958, **31**, June, 314–315). The rolling of larger slabs, up to 8000 lb wt, has been made possible at Shepcote Lane Rolling Mills Ltd. by application of the hot Steckel principle, whereby the strip, between passes, is coiled in furnaces at either side of the mill. Brief details and illustrations of the installation are given.—G. F.

Controlled Low-Temperature Hot Rolling as Practiced in Europe. R. W. Vanderbeck. (*Weld. J.*, 1958, **37**, March, 114-s–116-s). In some European mills the final hot rolling passes are effected at lower than normal temperatures (ending below 1600° F). This practice appears to result in an average improvement in the 15 ft-lb V-notch Charpy transition temperature of 20–45° F.—A. G.

New Continuous Terne Metal Line at Warren Plant of Republic Steel Corp. (*Ind. Heat*, 1958, **25**, May, 980). The new plant for the production of roofing terne includes an 80 ft acid cleaning tank, a dip tank holding 36-t of metal, a lap welder for joining base metal coils and an automatic branner to ensure a bright finish. Production will be 500 t per month.—A. G.

Stainless Steel Processing Requires Special Rolling and Annealing Techniques. (*Ind. Heat.*, 1958, **25**, March, 472–476). Techniques employed at the Wallingford Steel Co., Connecticut for the rolling and annealing of stainless steels are briefly described.—A. G.

Measurement of the Coefficient of Friction in Cold Strip Rolling. H. Yamanouchi and Y.

Matsuura. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 57–62). The method of measurement consists in entering strip into a specially designed two-high mill, and applying an increasing back tension until the neutral point is forced to the exit, the total frictional force being then in the same direction. The values at this stage of the roll force, torque, radius of deformed roll and the yield stress of the strip give the required coefficient of friction.

Large Reversing Drives: Mercury Arc Converters. (*Iron Steel*, 1958, **31**, June, 332–333). The possibilities of using mercury arc converters for large reversing drives are examined, and details are given of the principle of operation and the alternative methods of use. It is suggested that there is a strong case for using such converters for reversing steel mill duty both on technical and economic grounds.

Mercury Arc Converters for Large Reversing Drives. (*Brit. Steel.*, 1958, **24**, June, 186–188). Various installations are briefly described.

On Straightening Sheet Iron by Means of Various Sources of Heat. J. Matas. (*Zváranie*, 1958, **7**, (7), 219–220). [In Czech]. The straightening of sheet 0·15 in. thick or less by means of the application of hot spots is described. For thin sheet a shorted carbon arc can be used as source of heat, with thicker sheet the oxy-acetylene flame can be utilized.

Electromagnetic Control of Rolling Mill Machinery. A. Asbury and H. Law. (*Autom. Prog.*, 1958, **3**, Aug., 294–297). Uniselector control with programming is described.

Servo-Control of Strip Thickness in Rolling Mills. P. R. A. Briggs. (*Autom. Prog.*, 1958, **3**, Aug., 291–293, 297). A method using the elastic deformation of the mill itself and screw position is used to adjust screws or strip tension. An additional gauge allows for thermal changes.

MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

Transport in Iron and Steel Works, Uses of Conveyor Belting. A. C. Brandani. (*Iron Coal Trades Rev.*, 1958, **176**, June 27, 1551–1553). Installations in an integrated steelworks are described, and control, personnel and costs are considered.

LUBRICATION

Lubrication at Velindre. (*Sci. Lubr.*, 1958, **10**, May, 13–16, 18, 20, 22–23, 25–28). The systems used for the rolling, annealing and tinning lines and for motors, centrifuges and hydraulic systems are described.

WELDING AND FLAME-CUTTING

On Welding Cold Grey Cast-Iron. R. Krňák. (*Zváranie*, 1958, **7**, (3), 69–73). [In Czech]. The strength of test welds made with various electrodes was used as an electrode quality index. A newly introduced electrode "E-Bimetal," which is considerably cheaper than the electrodes "E-Nikelit" and "E-Bronz," was found to be satisfactory for weld repairs on cast-irons. The cast-iron used in the experiments contained 2·86%C as graphite and 0·56%C in combined form. The content of silicon was 1·87% or, in some, tests 2·45%.

On Welding Grey Cast Iron Without Pre-Heating. L. Muencner. (*Zváranie*, 1958, **7**, (3), 73–74.) [in Slovak]. (See preceding abstract). This paper deals with practical aspects of weld-repairs on cast iron castings, particularly with the choice of easily accessible electrodes and the strength and fatigue resistance of welds. A standard electrode recently developed by the Czechoslovak Weld-Research Institute, denoted by "VUS-Bimetal" was found to give good results in practice.—P. F.

Flame Welding Applied in Repairs of Grey Cast-Iron Machine Components. V. Mutňanski. (*Zváranie*, 1958, **7**, (7), 213–218). [In Slovak]. The choice of the correct welding procedure in flame welding cast-iron components or damaged machinery is discussed.

Welding Quenched Low-Carbon Steel. W. Gilde. (*Avtom. Svarka*, 1958, (2), 3–8). Large-scale experiments were carried out with a new O.H. structural steel St.37 of composition: 0·13%C; 0·25%Si; 0·45%Mn; 0·045% S; 0·034%P; 0·005%N. Its mechanical properties are yield stress before quenching 39·4 kg/mm² after quenching 55·9 kg/mm²; relative elongation before quenching 30·8%, after quenching 22·8%. Tests for hardness and fatigue of welds have shown good results.—L. H.

Schedules for Spot Welding Projection Hardware to Mild Steel Sheet and Plate. O. K. Barnes jun. (*Weld. J.*, 1958, **37**, March, 207–219). Electrode requirements, welding current values, electrode forces and cycles of weld time have been determined for a wide variety of hardware-to-sheet thickness combinations.—A. G.

Semi-automatic Welding of Parts Made of Thin Steel. I. I. Zaruba and G. M. Gologovskii. (*Avtom. Svarka*, 1958, (3), 79–82). The experiments have demonstrated the superiority of semi-automatic electrode welding of thin steels in a CO_2 atmosphere in comparison with other methods such as electric arc hand or oxy-acetylene welding.—L. H.

Welding Corrosion-Resisting Steels of the 18/8 Cr/Ni Type and Heat-Resisting Steels. F. A. Ball. (*Sheet Met. Ind.*, 1958, **35**, June, 439–452). Metallurgical factors are reviewed. Steels of the 300 series (austenitic) and the phase constituents of weld metal and methods of testing are given and then weld decay and its detection are discussed. Procedures are outlined.

Welding of thin "Chromansil" Steel Sheet in a Protective Atmosphere of Carbon Dioxide. N. I. Kakhovskii. (*Avtom. Svarka*, 1957, (6), 55–58). Experiments have shown that for the automatic and semi-automatic single pass, one and two-sided weld in a carbon dioxide atmosphere of steel 30KhGSA, it is best to use CV-10GSM wires. The composition of steel 30KhGSA is 0·26–0·38% C; 0·8–1·1% Mn; 0·9–1·2% Si; 0·8–1·1% Cr; 0·03% S; 0·035% P; 0·30 % Ni; 0·25 %Cu; the composition of the welding rod is not given.

Welding of High Chromium Steel 2Kh13 in a Carbon Dioxide Atmosphere. N. I. Kakhovskii. (*Avtom. Svarka*, 1958, (4), 44–54). This study refers to steel type 2Kh13 (0·18% P; 14·09% Cr; 0·6% Mn) and investigates the optimum conditions for welding in a CO_2 atmosphere, the possibilities of using austenitic wires, the resistance to cold cracking, the impact strength, the microstructure of the welds, tests for mechanical properties of welds, their tendency to thermal ageing and their resistance to fatigue.—L. H.

Electric Arc Welding of Heat Resisting Austenitic Steel Type 15–35. V. V. Kyrchenov. (*Avtom. Svarka.*, 1958, (5) 45–61). The composition for a weld metal has been worked out, an austenite-carbide type similar to the alloy elements of the steel (15% Cr and 35% Ni) with addition of carbon and niobium. Niobium plays a decisive role in joining the metal to the stable austenite.—L. H.

Welding Metallurgy of Cr–Mo–V Steels for High-Temperature Steam-Turbine Components. R. J. Christoffel, R. M. Curran, F. H. Domina and C. H. Soldan. (*Welding J.*, 1958, **37**, July. 295s–303s). Procedures which are described, and which were adopted for welding Cr–Mo–V steel—as used for components operating at 1050° F—with 0·5 Cr–1·0% Mo electrodes, gave a weld rupture strength less than that of the parent metal, both with manual and submerged-arc welding. A Cr–Mo–V electrode gave improved results.

Welding Heat Resisting Steel Quality 20KhMF in a Carbon Dioxide Stream. B. S. Kasatkin and Yu. N. Vakhnin. (*Avtom. Svarka*, 1958, (3), 3–11). The chemical composition of the steel investigated is: 0·18–0·25% C; 0·20–0·35% Si; 0·4–0·6% Mn; 0·9–1·2% Cr; 0·5–0·7% Mo; 0·2–0·3% V; and less than 0·03% S or P. The tests determined the optimum composition of the electrode wire for the welding of this steel, a composition not much different from the composition of the steel, and also investigated the properties and structure of the weld, the value of the hardness and the resistance to temperatures up to 500°.—L. H.

Welding of Chromium–Nickel Austenitic Steels and Heat-Resisting Alloys with Lamellar Coated Electrodes. B. I. Medovar, Yu. V. Latash and A. N. Safonnikov. (*Avtom. Svarka*, 1958, (2), 9–19). The technique and technology of welding these steels in rods with a cross-section of up to 30·000 mm² was worked out. By using fluoride fluxes an almost complete elimination of the easily oxidizable impurities (Al, Ti, B) from the base and electrode metals into the weld is obtained.—L. H.

The Possibility of Attaining an Equilibrium Relation in the System Slag–Metal in Electric Arc Welding. E. D. Lonskii. (*Avtom. Svarka*, 1958, (4), 72–83). The investigation extends to the metallurgical conditions for the passage of Mn into the fused-on metal according to the relation $[Mn]_{\text{fused-on metal}} = f\dfrac{(MnO)}{(FeO)}$ based on the oxidation reaction $[Mn] + (FeO) \rightleftharpoons (MnO) + [Fe]$. The influence of the electrodes made of rods of different steels, with different coverings of ferro-alloys and with two-component coverings have been investigated.

Attachment for Increasing the High-frequency in Twin Point Electric Welding. Yu. A. Pachentsev. (*Avtom. Svarka.*, 1958, (4), 55–58). An attachment is described type K–132, which is recommended as most suitable for welding sheets of large size as facings to large structures. The relatively small sizes of these attachments make it possible to use them as autonomous welding tools in multi-electrode machines.—L. H.

Comparative Properties of Electrodes for Arc Welding Austenitic Manganese Steels. H. J. Chapin. (*Welding J.*, 1958, **37**, July, 702–705). A discussion of the paper under the above title by Lutes and Reid (1956, **35**, Aug., 776–783). This paper is criticized mainly on the grounds that the analyses of the various Hadfield manganese-steel welds were too variable, and some elements were out of specification. The effect of various factors on the mechanical properties of the specimens is then discussed.

Assessing Fluxes for Automatic Submerged-Arc Welding. J. Zeke. (*Zváranie*, 1958, **7**, (4), 97–101). [In Slovak]. The effect of physical properties, such as thermal and electrical conductivities, boiling point, density and surface tension of several fluxes, as well as their composition, e.g. CaF_2 content, on their suitability for automatic submerged-arc welding were investigated. A new flux "VUS-34Mn," which is now entering the production stage, was found to be superior to the flux Z-41 hitherto currently used in Czechoslovakia for such purposes. The physical constants obtained and the chemical composition of the fluxes are given. Z. Duben, in the discussion of the article, questions the admissibility of the quality scale of Czechoslovak fluxes advanced by J. Zeke, on the grounds that certain important factors, such as the mechanical properties of the welds, the importance of the ignition peak on welding with a.c. and its relation to flux characteristics, economic aspects etc. were not at all or inadequately allowed for in that assessment.—P. F.

Ceramic Flux KVS-19 for the Automatic Welding of Low Carbon Steel. A. G. Mazel' and R. P. Burlakova. (*Avtom. Svarka*, 1958, (3), 62–68). The chemical composition of this flux is manganese ore 54%, CaF_2 7%, quartz sand 30%, Fe–Si 7%, Al powder 2%. The process of manufacture and results of tests are given. Its use is recommended for the automatic and semi-automatic welding of low carbon steels.—L. H.

Investigation of the Flux ANF-5 for the Automatic Welding of Steel 1Kh18N9T. N. I. Gerasimenko and S. I. Zagurnyi. (*Avtom. Svarka*, 1958, (3), 90–92). This flux without oxygen was tested in 1956. Its composition is: CaF_2 75–80%; NaF 17–25%; SiO_2 less than 2%; S less than 0·05% and P less than 0·02%. The results have proved better than with comparable fluxes as regards resistance to cracks, corrosion and mechanical properties.

Influence of Carbon, Phosphorus and Nickel on the Cold Brittleness of Weld Seams on Steel 12N3. S. A. Ostrovskaya. (*Avtom. Svarka*,

1958, (2) 42–52). The cold brittleness of these seams is influenced by chemical composition and structure. The presence of carbide-forming elements and a non-uniform structure lowers the resistance of the metal to the transition to a coarser structure. Increasing nickel content in the weld metal lowers the threshhold temperature of cold brittleness. Carbon content up to 0·1%, phosphorus up to 0·03% and Ni up to 1% increases the resistance of the weld metal at temperatures down to — 70°.—L. H.

The Structure and Properties of the Zone in Contact with the Weld of Steel 8Kh13. N. I. Kakhovskii. (*Avtom. Svarka*, 1958, (2), 30–36). Investigations on the weldability of this steel and the microstructure of the zone next to the weld have shown that in thicknesses up to 12 mm, this steel can be efficiently welded without preheating, but, during welding, non-uniformity of structure develops in the zone adjoining the weld and tempering of the weld at 700–750° is necessary.—L. H.

Experimental Results of the Slag–Metal Interaction in Manual Arc Welding. M. Okada and H. Nakamura. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1957, **7**, Oct., 425–437). Two stages are recognized and the conditions in both are investigated.

Role of Phosphorus in Austenitic Manganese Weld Metal. W. T. De Long, W. L. Lutes and H. F. Reid jun. (*Welding J.*, 1958, **37**, July, 316s–319s). Phosphorus concentration in austenitic manganese weld metals has an important influence on the properties of the weld deposit. 0·035% P appears to be the maximum that can be tolerated, and Ni–Mn deposits had outstandingly good properties in the range 0·01 to 0·02% P. Low phosphorus Mo–Mn weld metals also showed improved properties.

Metal Structure of the Weld Metal in Slag Electrode Welding of Carbon Structural Steels. S. A. Ostrovskaya. (*Avtom. Svarka*, 1957, (6), 43–54). The structure and orientation of the crystals in electro-slag welded seams depends on the conditions of operation and the composition of the metal in the seam. Four types of seams have been conditioned in these carbon structural steels by the variations in the conditions of welding.—L. H.

Intercrystalline Diffusion in the Fusion of Copper and its Alloys on to Steel. I. I. Dzhevaga. (*Avtom. Svarka*, 1957, (6), 87–90). The diffusion of one metal into the other can proceed within the grain and also along its boundaries. Generally the diffusion along boundaries is more intensive but a number of factors influence this diffusion process during oxy-acetylene welding.—L. H.

Low Crack Sensitivity of Steel Joints by CO_2–O_2 Arc Welding. H. Sekiguchi and I. Masumoto. (*Welding J.*, 1958, **37**, July, 326s–336s). The authors give an outline of a welding process recently developed in Japan, using a CO_2–O_2-shielded arc, with a bare steel wire electrode containing sufficient deoxidants to prevent blowhole formation in the weld metal. The properties of the joints are then compared with those made by other welding methods—in particular, hydrogen content and hence crack sensitivity are less with the new process.

Energy Absorption Studies of Welds in Tempered Martensitic Base Metal. W. H. Bruckner and C. A. Robertson. (*Weld J.*, 1958, **37**, March, 97s–100s). Tensiou-impact test results provide a comparison of the behaviour of T-I grade steel with steels of killed or rimming grade and permit its merit in overcoming low temperature fracture to be evaluated. The micro-mechanism of failure has also been studied.—A. G.

Stress-Relaxation Tests on Welded Specimens of Consett "Low-Tem" Steel. A. J. Fenner and A. Cowan. (*U. K. Atomic Energy Authority Industrial Group, Tech. Note*, 113, *TRDC/P.* 89, pp. 11). Stress-relaxation tests were carried out on plate and welds in creep testing machines at 350° and 400° C and heat treatment of bars strained in bending was examined. The apparatus used and curves of residual stress and relaxation are shown.

Fatigue Characteristics of Single-Lap Joints of AISI 347 Brazed with a Ni–Cr–Si–B–C Alloy. R. G. Aspden and W. Feduska. (*Weld. J.*, 1958, **37**, March, 125-s–128-s). At room temperature the brazed single lap joint had an endurance limit equivalent to the original AISI 347 annealed strip, but this fell to 90% at 1100° F. A mechanism of fatigue cracking in these brazed joints is put forward.

Vibration Tests for Welds of Steel MSt3 Containing up to 0·15 As. A. E. Asnis. (*Avtom. Svarka*, 1958, (3) 24–34). Cylindrical specimens were subjected to vibration tests of not less than $5 \cdot 10^{-4}$ cycles before rupture. Specimens from the same steel, but with flux welded cross-sections were subjected to the same tests. Welding was done with a current of 700 amp at a rate of 25 m/h and included also rimmed and killed steels. Steels without arsenic have a greater plasticity than arsenic-containing steel.—L. H.

Evaluation of the Kinzel Test from its Fracture Characteristics. R. D. Stout, W. J. Murphy and R. C. Westgren. (*Weld. J.*, 1958, **37**, March, 107-s–113-s). The observed effects of plate composition, welding conditions and heat treatment on the transition temperature are related to changes in the ability of various regions at or near the weld to initiate or resist cleavage fracture. Limitations of the Kinzel test are discussed.—A. G.

Prediction of Welded Heat-Affected Zone Microstructures from Continuous-Cooling Transformation Data. E. F. Nippes and E. C. Nelson. (*Welding J.*, 1958, **37**, July, 289s–294s). Experiments are described to show that the microstructures of the heat-affected zones of welds can be predicted theoretically from continuous-cooling transformation diagrams. Fairly good agreement was found between calculated and experimental results, with a few exceptions.

Investigation of the Non-Metallic Inclusions in Welds with Flux. V. V. Podgaetskii, N. A. Langer, Yu B. Malevskii and G. P. Manzhelei. (*Avtom. Svarka*, 1958, (4), 10–23). A detailed study, taking into account the conditions of the operation, composition of the weld metal, methods of determining the total quantity and composition of the non-metallic inclusions and their distribution, the influence of the fluxes and of the primary structure in the appraisal of the findings.

Fundamentals of Brazing for Elevated-Temperature Service. M. D. Bellware. (*Welding J.*, 1958, **37**, July, 683–691). The selection of suitable brazing alloys and methods of working are described for such purposes as jet turbine blade and heat exchanger fabrication.

Brazing—Indefinitely Indispensable. P. D. Johnson. (*Met. Treating*, 1958, **9**, Mar.–Apr., 2–5, 49–51). A general account of brazing practice.

Dry Hydrogen Brazing for Complex Stainless Assemblies. H. Lewis. (*Western Metalw.*, 1958, **16**, Apr., 52). A general outline of the process and its advantages is given.

Salt Bath Brazing. L. B. Rosseau. (*Ind. Heat.*, 1958, **25**, July, 1325–1326, 1328, 1330, 1332, 1334, 1346). Dip brazing processes are described.

Combustion of Liquid Hydrocarbon Fuels for Oxygen Cutting. D. Khuong-Huu, S. S. White and C. M. Adams. (*Weld. J.*, 1958, **37**, March, 101-s–106-s). The characteristics of a liquid fuel cutting torch using white, unleaded gasoline as the preheat fuel have been studied. The determinations by Sachsse and Bartholomé of computed flame temperatures have been summarized in a single quantitative relationship.—A. G.

MACHINING AND MACHINABILITY

Influence of Vibrations on Tool Life and Surface Condition in Milling Operation. H. Opitz. (*Microtecnic*, 1958, **12**, April, 72–87). Effects on single-point and multi-point tools are evaluated. The effect of torsional vibrations on tool life is then considered and milling drives and methods of damping are reviewed. Effects on surface condition are finally examined.

Contribution to the Study of Ceramic Cutting Tools. R. Weill. (*Microtecnic*, 1958, **12**, April, 51–63). The constitution and physical properties of the materials are given and a comparison of the results obtained with a French-made ceramic and two carbide tools is made. The temperature resistance appeared to be the factor favouring ceramic tools. Wear tests on cast iron were made and impact tests were carried out. Points to be taken into account in the use of ceramic tools are listed.

Coolant Heated to Hold Tolerances. (*Metalw. Prod.*, 1958, **102**, Aug. 15, 1434–1435). A case where large shafts and jet engine hubs were oversize on coming up to room temperature is described. The coolant on a light grinder was therefore raised to gauge temperature.

Special Machines Make Fluted Rolls. P. Trippe. (*Metalw. Prod.*, 1958, **102**, Aug. 22, 1463–1467). The production of chilled cast iron rolls for flour mills with a fine-pitch helical fluting is described.

Device for Recording the Zone of Deformation when Cutting Metals. B. G. Levin. (*Vestnik Mashin.* 1958, (7), 63–64). The device evolved and constructed at the Leningrad Branch of the All Russia Technological Institute is described. The specimens under test are cut in 0·001 sec. This device makes it possible to investigate the structure of the deformation zone i.e. the root of the chip.

Increasing Durability and the Precision of Turning of Parts made from Steel 18KhGT. A. V. Pakhomov. (*Vestnik Mashin.*, 1958, (7), 69–70). The increase in the durability of metal cutting tools and a clean working surface of the parts may be attained by introducing in the cutting zone an alternating current of low voltage but of large power. The adaptation of the lathe and the necessary theoretical explanations are supplied and graphs are given plotted with the findings from metallographic investigations of the microstructure of the surfaces.—L. H.

CLEANING AND PICKLING

Cleaning Stainless Steel Parts and Products. W. E. McFee. (*Prod. Fin.*, 1958, **11**, April, 56–59). Recommended methods are given for cleaning stainless steels before and after welding or soldering and for eliminating embedded metal and grease stains.—A. G.

Ultrasonic Cleaning of Steel Strip. (*Sheet Met. Ind.*, 1958, **35**, June, 460–461). The method as used in the Kaltwalzwerk Brockhaus, and the Schade Works, Plettenberg, is briefly described. The equipment was supplied by Schoeller & Co., Frankfurt.

Shot-Blasting Ships' Plates. (*Metalw. Prod.*, 1958, **102**, Aug. 15, 1436–1438). Installations at two yards of airless shot-blasting plant for descaling ships' plates are described and illustrated.

Flame-Priming of Steel Surfaces in Mine Applications. G. H. Morgan. (*Can. Min. J.*, 1958, **79**, July, 77–80). Flame cleaning before painting and its uses are described.

Nitrogenous Coal-Tar Bases as Pickling Inhibitors for Steel in Acids. N. D. Rus'yanova, M. V. Goftman and L. A. Burmistrenko. (*Zhur. Prikl. Khim.*, 1958, **31**, (5), 748–754). An experimental investigation is described of the corrosion-inhibiting action of coal-tar base distillation fractions, and of some pure compounds and by-products from their isolation from crude bases. In the first stage, type-3 steel plates were immersed in 12% H_2SO_4 and 15% HCl for 20 h at room temperature or 2 h at 70 ± 2° C. Further experiments showed that even small concentrations (0·02%) of KCNS greatly increases the inhibiting action of bases in sulphuric acid, the effect increasing with concentration and applying to a wide variety of steels and to cast iron. Base-thiocyanate mixed inhibitors are recommended for pickling of ferrous metals.

Evaluation of the Blaw-Knox–Ruthner Pilot Plant Program. J. H. Strassburger. (*A.I.S.I. Preprint*, 1958, pp. 24). The author discusses the Blaw-Knox–Ruthner pilot plant programme for the recovery of waste pickle liquor, first outlining the chemistry of the

process and then giving details of the pilot plant. The question of economics is also studied, and manufacturing costs are estimated and compared with those of lime neutralization. Finally, the efficiency of the process is outlined.—G. P.

PROTECTIVE COATINGS

Factors Affecting Residual Stress in Electrodeposited Metals. J. B. Kushner. (*Met. Fin.*, 1958, **56**, May, 82–87; June, 56–60; July, 52–55, 59). The effects of cathode films, temperature, current density, contaminants and additives are reviewed and the role of the metal surface is surveyed. After-effects and hydrogen uptake are finally considered. Summarizing, an equation connecting stress with thickness of deposit is proposed, effects of anions on overvoltage has no connection with stress, very low temperatures greatly lower cathode efficiency and increase stress, very low current densities also increase stress somewhat. Impurities, grain size and surface cleanliness affect stress but surface finish has little effect. A theory of the cause of stress is advanced depending upon the behaviour of water molecules and trapping of residues of coordination compounds or of complex cations.

Cleaning and Plating Steel Assemblies. N. Ananiatis. (*Met. Fin.*, 1958, **56**, June, 65). Typical cycles are briefly indicated.

Cavitation Resistance of Electrodeposited Chromium. M. G. Timerbulatov and V. E. Khromov. (*Vestnik Mashin.*, 1958, **38**, (2), 56–58). Tests were carried out with a magnetostrictive vibrator in water at 25° C with a frequency of 8300 c.p.s. and an amplitude of 60μ for 3 h. Hardness was measured and bright and matt coatings deposited under various conditions were used. Minimum plating thickness for protection was 50μ, but should be thicker for severe conditions. Matt finishes were more resistant than bright.

Finishing Pointers: Use of a Nickel Plating Bath as an Analytical Standard. J. B. Mohler. (*Met. Fin.*, 1958, **56**, May, 88). Approximate analysis of plating baths for Ni, chloride and boric acid are described using a made up bath approximating to plating concentrations as standard.

Studies in Electroless Plating. C. de Minjer and A. Brenner. (*N.B.S. Tech. Bull.*, 1958, **42**, May, 86–87). Rate of deposition (of Ni + 8% P) has been studied at different pH values, the optimum being found at 4–4·5. Lower acidities increase the rate, but nickel phosphite precipitates. Organic acids used in buffering had specific effects. Various catalysts and catalyst poisons, such as thioureas, were tested. Exposure tests were also made.

Galvanizing the Modern Way. (*Gas World*, 1958, **148**, Aug. 16, 32–33). An account of the use of gas heating as dealt with at the 5th International Conference at Scheveningen and Knokke-le-Zoute.

The Effect of the Relative Contents of Sodium Cyanide and Hydroxide in Electrogalvanising Baths on the Mechanical Properties of Steel. L. I. Moroz and N. T. Kudryavtsev. (*Metallov. Obrabotka Met.*, 1958, (4), 25–28). Two steels were studied for development of brittleness due to H_2 absorption by means of bend tests. Increase of NaCN impairs the ductility. The least change was observed with an electrolyte containing 1–1·5 g. equiv./l NaCN, 2·5–3 g equiv./l NaOH and 1 g. equiv./l Zn.

The Effect of Lead in the Galvanising Bath on the Ductility of Galvanised Coatings on Steel. M. A. Haughton. (*Sheet Metal Ind.*, 1958, **35**, **June**, 453–458). It is concluded that lead has no appreciable effect on coating weight or ductility.

A Study of Surface Carbides, Differential Steel Attack and Pore Formation in the Galvanizing Process. J. J. Sebisty. (*Canada Mines Research Report R6*, 1958, Mar. 14, pp. 18). Carbide inclusions have an effect on coating structure depending on temperature and Al content. Surface working was related to degree of galvanizing attack, the rubbed sheet being more reactive. Pore defects appeared to be due to gas evolution accompanying the flux reaction.

The Influence of Aluminium, Lead and Iron on the Structure and Properties of Galvanized Coatings. J. J. Sebisty and J. O. Edwards. (*Canada Mines Research Report, R5*, 1958, Mar. 14, pp. 47). Immersion time and Al content were the most significant factors in coating weight, steel loss, Fe content and alloy growth in the coating, ductility and adhesion. Lead had most effect on surface appearance. Corrosion tests suggested that Al and to a lesser degree Pb promoted "white rusting."

Control of Tinning Lines at Velindre. (*Engineer*, 1958, **206**, Aug. 15, 262–266). The electrical equipment is described.

Electric Melting in the Tinning of Iron Strip by Induction Heating. F. Alf. (*Elektrowarme*, 1958, **16**, Aug., 283–288). The process and plants already installed are described.

Aluminising of Steels by the Aqueous Flux Process. S. M. Arora, P. K. Gupte and B. R. Nijhawan. (*Trans. Indian Inst. Met.*, 1958, **11**, June, 57–72). Steel is degreased with CCl_4, pickled for 10–20 sec. in hot conc. HCl at 60–80° C, dipped in a KF solution as flux, dried and dipped in Al for 15–30 sec. at 710–760° C. Adhesion tests are described.

Metallizing and its Application in Aircraft Gas-Turbine Components. D. E. Hacker. (*Weld. J.*, 1958, **37**, March, 231–238). The selection of proper spray material, base metal preparation, spraying technique and machining of the deposit are emphasized. Testing methods for coatings are described and specific applications of metallizing are mentioned.—A. G.

Protection of Chemical Plant by Organic Coatings. J. R. Rischbieth. (*Society of Chemical Industry of Victoria*, 1956, **56**, 11–18). A short summary of surface preparation, coating thickness and types of plastics, bitumen and rubber products.

Finishing Kenwood Mixers. (*Prod. Fin.*, 1958, **11**, April, 91–95). Aluminium alloy castings are first given a hot alkali dip followed after rinsing by treatment with nitric acid. Steel parts are degreased with trichlorethylene. After priming and filling, parts are sprayed with an epoxy ester amino-resin finish and stoved.—A. G.

POWDER METALLURGY

Present State and Future Prospects of Powder Metallurgy in Rumania. A. Domsa. (*Met. Constr. Masini*, 1958, (4), 287–290). [In Rumanian]. The article reviews the state of the industry which does not as yet produce metal powders on a large scale. Much research work is being done and experimental machines evolved for production of steel and other powders. The study also extends to non-ferrous powders which are obtained by electrolysis or from the liquid phase and also by reducing iron by methane. The availability of methane gas for reducing iron oxides has a great future.—L. H.

Electrolytic Iron Oxide—Production and Properties. W. M. Schafer and C. R. Harr. (*J. Electrochem. Soc.*, 1958, **105**, July, 413–417). A general account of production and analyses, density, particle size, pressing and sintering properties and the hardness and tensile properties of sintered products and their magnetic values is given.

Sintered Iron-Base Alloys for Machine Parts (VII). Gas Carburisation of Sintered Iron-Base Compacts. Y. Fujii, E. Hayashi, T. Watanabe and M. Yasuda. (*Rep. Gov. Ind. Res. Inst.*, 1958, **7**, June, 412–420). Compacts expand during carburizing and quenching, increasing with time and decreasing with pressure . The case depth with reduced is less than with electrolytic powders under the same conditions. Iron–copper compact expands depending upon the Cu content, intercommunicating porosity is greater and so case depth increases unless Cu is very high.

Investigation of Porous Iron Bearings with Improved Resistance to Wear. G. Dan, O. Stefan and A. Protopopescu. (*Studii si Cercetari de Metalurgie*, 1957, **2**, (4), 465–481). Pure iron is not a suitable material for bearings but oxide powders from hot-rolling mill scale of normal non-alloy steels, with a density of ca. 2·78 have proved suitable. Sintering in methane and sulphiding has produced bearings comparable with those made from electrolytic iron.—L. H.

Production and Use of Hydrogen and Dissociated Ammonia Atmospheres for Sintering Powdered Metals. M. R. Ogle. (*Ind. Heat.*, 1958, **25**, July, 1356, 1358, 1360, 1362, 1364, 1484).

Slip Casting of Metal Powders. H. H. Hausner. (*Powder Met. Bull.*, 1958, **3**, June, 53–57). The process is described and the analysis and particle size of stainless steel powder and the effect of various factors on the sintered products are given.

Tensile Strength of Sintered Iron Powder as a Function of Surface Area and Particle Shape. P. R. Basford and S. B. Twiss. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 124–131). The authors have determined the relationship between tensile strength and areas of iron powders, briquettes and sintered compacts, distinguishing between the macroscopic area due to particle shape and size and the microscopic area due to surface pores and cracks. Only the macroscopic area contributes to tensile strength. Other important factors determining the strength of sintered compacts are density and the presence or absence of surface oxide.—G. P.

FERRITES, CERMETS, AND CARBIDES

Magnetic Properties of the Nickel and Cobalt Ferrite–Chromite Series. S. Miyahara and T. Tsushima. (*J. Phys. Soc. Japan*, 1958, **13**, July, 758).

Effect of Gases during Heating on the Magnetic Properties of [Mn–Zn] Ferrites. C. Heck and J. Weber. (*Arch. Eisenhüttenwesen*, 1958, **29**, Aug., 495–504). Temperature and additions of flux are also discussed.

The Rate of Infiltration of Metals. K. A. Semlak and F. N. Rhines. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 325–331). Given certain assumptions, it was found that the rate of capillary rise of liquid metals in porous-metal bodies can be described by the expression:

$$h = 2/\pi \left(\frac{R_e \gamma \cos \theta t}{2\eta}\right)^{\frac{1}{2}}$$

where h is the height of rise of liquid in the body, R_e the average capillary radius of the body, γ the liquid-gas surface tension of the liquid component, t the time of rise, η the viscosity of the liquid metal and θ the liquid-solid contact angle. It was found possible to determine the effect of several experimental variables on the rate of infiltration.

PROPERTIES AND TESTS

Metals—Their Use and Testing. L. E. Benson. (*Trans. Manchester Assoc. Eng.*, 1954–1955, 23–51, discussion 51–58). A miscellaneous collection of topics concerning iron and non-ferrous metals are discussed including the testing of rotor forgings, segregation in large ingots, magnetic and ultrasonic testing methods, castings, tubes, stress-corrosion cracking and the comparison of wrought iron and steel chains.

S-Curves of 9 Czechoslovak Low-Alloy Structural Steels. J. Váňa. (*Hutn. Listy*, 1958, **13**, (4), 308–313). [In Czech]. Liedholm's as well as a dilatometric method were used to obtain S-curves of the steel during gradual cooling.—P. P.

Surface Quality of Annealed Hypoeutectoid Steel. V. I. Dauknis. (*Metallov. Obra. Met.*, 1957, (1), 56–59). The depth of the hardened layer created by the process of polishing and the cleanliness of the polished surface depend on all the factors associated with polishing except the speed of rotation of the part. An increase in the transverse and longitudinal feed causes an increase in the depth of the hardened case and adversely affects surface quality. An increase in peripheral speed of the polishing wheel slightly reduces the depth of the hardened case and improves surface quality.—R. S.

Measurement of Casting Surface-roughness. C. H. Good and C. E. McQuiston. (*Foundry*

Trade J., 1958, **105**, Aug. 14, 191–195). Methods of measurement are reviewed and the stylus-type instrument is particularly recommended.

Radioactive Tracer Study of Steel Surface Defects. T. W. Crosta. (*J. Met.*, 1958, **10**, Apr., 285–289). By admixture of radioactive ^{140}La, it has been shown that the facing slurry applied to hot-tops is a main source of exogenous slag inclusions in the ingot at Algoma Steel Corp. This is particularly the case when the hot-top is insufficiently dried and with a spraying stream.—G. F.

Piezoelectric Method of Measuring Surface Roughness. I. V. Dunin-Barkovskii. (*Vestnik Mashin.* 1958, (7), 61–62). A prototype, piezoelectric profilemeter has already proved superior to the induction type instrument, since it gives a margin of error of ± 15% against ± 25% for the latter type. Furthermore it works at one quarter the speed and generates 1000 times the voltage of the induction type. Its use is recommended for tests under conditions of production.—L. H.

Internal Friction, a Useful Physical Quantity in Metallurgy (2). B. Rothenstein and J. Hrianca. (*Met. Constr. Masini*, 1958, (2), 109–116). (See 1957, 11). This article carries a summary covering the fundamental theories and their practical applications in connection with the interstitial atomic diffusion in solid solutions and with the study of phase transformations by measuring internal friction. These studies have been carried out at the physical laboratory of the Polytechnic Institute of Timisoara.—L. H.

An Improved Design for Cast Tensile Bar Molds. M. Karnowsky. (*Mod. Castings*, 1958, **33**, June, 88–91). Modifications to a tensile bar mould are described, which reduce turbulence due to the dam and runner design, eliminate unfilled runners and give nearly equal filling of the cavities from each of the in-gates.—A. G.

The Effect of Tension on the Magnetostriction of Iron Single Crystals. H. Takaki and J. Hayashi. (*J. Phys. Soc. Japan*, 1958, **13**, July, 703–709).

Measurement of Magnetic Permeability of Liquid Metals. A. A. Vertman and A. M. Samarin. (*Zavods. Lab.*, 1958, (3), 309–310). A special apparatus is described by which the magnetic properties of liquid metals can be compared quantitatively by relating them to a known permeability x_1. With this apparatus the magnetic permeabilities of the systems Fe–Ni, Ni–Co and Fe–Si were measured at temperatures in the region of 1700°.—L. H.

A Ferrometer for the Determination of the A.C. Magnetization Curve and the Iron Losses of Small Ferromagnetic Sheet Samples. H. Blomberg and P. J. Karttunen. (*Proc. I.E.E.*, 1958, **105A**, Aug., 375–384). **Direct-Reading Iron-Loss Testing Equipment for Single Sheets, Single Strips and Test Squares.** J. McFarlane, P. Milne and J. K. Darby. (385–394). **The Control of Flux Waveforms in Iron Testing by the Application of Feedback Amplifier Techniques.** J. McFarlane and M. J. Harris. (395–402). **Discussion.** (402–405). **Magnetic Annealing of Fe_3Al Single Crystal.** K. Suzuki. (*J. Phys. Soc. Japan*, 1958, **13**, July, 756–757).

The Ultrasonic Beam Immersion Technique. J. Krautkrämer. (*SS News*, 1958, June, 7–18; from *Metallkunde*, 1957, Nov.). The process is outlined and the principles are illustrated, with the necessary formulae and consideration of pulse frequency and test speed.

Introduction to Ultrasonic Testing. (*S.S. News*, 1958, June, 12–18). Effects of compression and shear waves at iron—Perspex boundaries are shown and types of probe holders are illustrated.

Practical Applications of Ultrasonics for Non-Destructive Testing of Steel. E. Močnik. (*Varilna Tekhn.*, 1957, **6**, (3–4), 71–73). [In Serbocroat]. The uses of ultrasonics, particularly in thickness gauges and for flaw-detection in welds are discussed.—F. F.

X-Ray Structural Methods of Investigating the Mosaic Structure of Metals. Ya. S. Umanskii and L. Kh. Pivovarov. (*Zavods. Lab.*, 1958, **24**, (5), 549–554). This is a survey of Russian and foreign literature on the use of X-rays for determining the block structure and dimensions of metals and alloys, and for studying disorientation. Examples for ferrous and non-ferrous materials are given.

Camera for Diffraction Micro-X-Radiography. B. V. Sharov. (*Zavods. Lab.*, 1958, **24**, (5), 647–648). The camera briefly described is based on the "Seemann" universal X-ray camera. Preliminary experiments with visual observation of the image with a binocular microscope have shown that the camera can be adapted to this if a sharp-focusing tube is used.—S. K.

Electron Diffraction Studies of Crystal Structure of Oxides of Iron. A. Pande. (*J. Sci. Ind. Res.*, 1958, **17B**, June, 205–208). Effects of occluded H_2 are also determined.

Neutron-Structural Analysis of Metals and Alloys. B. G. Lyashchenko. (*Zavods. Lab.*, 1958, **24**, (5), 585–597). This is a survey of the application of neutrons to the study of metal and alloy structures including those of ferrous materials. The main features of neutron-diffraction analysis, some crystallographic applications and the application of magnetic scattering are dealt with.—S. K.

Irradiation of Steels. T. J. Heal. (*U.K. Atomic Energy Authority, Industrial Group, IGR-TN/C-651*, 1957, pp. 6 + iii). Research programmes are outlined, with comments. Lists of steels to be tested are given.

The High-Temperature Properties of Four Wrought Steels Used in the Chemical Industry. B. J. Connolly and G. Boyd. (*Proc. I.M.E.*, 1958, preprint, pp. 15). High temperature tensile and creep properties of a low-C 1% Cr–Mo steel, a medium-C 1%Cr–Mo steel, a low-C 3%Cr-Mo steel and an 18/10/Mo/Ti Cr–Ni austenitic steel. Applications to design are briefly considered.

Determination of the Rate of Diffusion of Hydrogen in Metals. R. A. Ryabov and P. V. Gel'd. (*Zavods. Lab.*, 1958, (3), 306–308). By means of a special apparatus, the relation between temperature and the rate of diffusion of hydrogen in various iron alloys with C, Cr, Si and other alloy elements was investigated, as it was also for a number of structural steels. This rate is based on the law of the square root of the hydrogen pressure at low temperature (ferrite–carbide structure), and at high temperature (austenite structure).—L. H.

Diffusion of Silicon and Manganese in Liquid Iron. I. Diffusion in Liquid Iron Saturated with Carbon. T. Saito and K. Maruya. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1958, **10A**, June, 259–268). Measurements were made between 1300–1600° and expressions for diffusion rate and activation energy values are given.

Diffusion of Third Elements in Liquid Iron Saturated with Carbon. R. E. Grace and G. Derge. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 331–337). The capillary-reservoir technique was used to determine the diffusion coefficients of S, Ni, Ti, Mn, P and Si in carbon-saturated liquid iron. Average rates of diffusivity of C in binary Fe–C alloys was measured between 1·5 and 5%C.

Solubility of Nitrogen in Liquid Iron and Iron Alloys. V. C. Kashyap and N. Parlee. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, Feb., 86–91). Using the Sieverts method, the authors have determined the solubility of nitrogen in liquid iron and liquid Fe–Ni, Fe–Mo, Fe–V, and Fe–Mo–V alloys. A method for predicting gas solubilities in complex alloys from solubility data on binaries was applied to the Fe–Mo–V alloy, reasonably good agreement being obtained between calculated and experimental solubilities.

Environmental Effects of Hydrogen Permeation Through Steel During Abrasion. D. E. Swets, R. C. Frank, and D. L. Fry. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, Apr., 219–220). Experiments show that the operations of sanding and grinding can cause hydrogen permeation through steel at rates considerably greater than that occurring during normal atmospheric corrosion. Anodizing and the addition of oxidizing agents to the cutting fluid markedly reduce the permeation rate.

Why Low Hydrogen Contents are Desirable in Steel. E. R. Slaughter. (*A.I.M.M.E., Proc. O.H. Comm.*, 1958, **39**, 114–117). Hydrogen is responsible for four main types of defect in steel, namely, porosity, flakes, embrittlement, and delayed brittle fracture. The author discusses these defects and considers the probable sources of H_2 responsible for them.—G. F.

Activity Measurement in the System Iron-Chromium. C. L. McCabe, R. G. Hudson, and H. W. Paxton. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 102–105). The authors have measured the activities of Fe and Cr in their binary alloy by the Knudsen orifice technique, and found the system close to ideal at 1200–1250° C. The effect of this on the liquidus and solidus is discussed, and these temperatures are calculated for two limiting assumptions. The vapour pressures of the pure elements measured by the Langmuir and Knudsen methods agree within experimental error at 1200° C.—G. F.

The Solubility and Activity of Titanium in Carbon-Saturated Iron. F. D. Delve. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr., 183–185). The author has determined the solubility of Ti in carbon-saturated iron under atmospheres of N_2, A and CO and identified the precipitated phases by X-ray diffraction. From the results, the activity of Ti in carbon-saturated iron is calculated.—G. F.

Enthalpy and Heat Capacity from 0° to 900° C of Three Nickel-Chromium-Iron Alloys of Different Carbon Contents. T. B. Douglas and A. W. Harman. (*J. Res. N.B.S.*, 1958, **60**, June, 563–568).

Influence of Mn, P and Si on the Activity of Aluminium in Liquid Pig Iron. V. I. Musikhin, O. A. Esin and B. M. Lepinskikh. (*Zhur. Priklad. Khim.*, 1958, **31**, (5), 689–693). In the work described the activity of Al in fused pig iron with the addition of P, Si and Mn was determined by an improved e.m.f. method. The cell used was Al Al_2O_3 Fe, Cast, Al, Me, where Me = Mn, P, Si, the temperature being 1250° C. It was found that the activity was not affected by Mn (up to 2·7%), while Si and P increased it. The use of concentration cells with solid electrolyte gave reproducible results and is recommended for activity determinations in ferrous metals.

Equilibrium between Cerium and Sulphur in Liquid Iron. F. C. Langenberg and J. Chipman. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 290–293). The relationship between Ce and S in iron at steelmaking temperatures was studied by melting pure iron in CeS, Al_2O_3, or MgO crucibles in a specially designed furnace under a neutral atmosphere (purified A), together with Ce and a Cr–Ni alloy. After melting, Ce or FeS was added. Similar trials were made in Al_2O_3 or MgO crucibles. The product [Ce%] [S%] was found to be $1·5 \times 10^{-3}$ at 1600° C.

Alloy Steel: Semi-finished: Hot Rolled and Cold Finished Bars. (*A.I.S.I. Steel Prod. Man. Supplement*, 1958, July, pp. 51).

Heat and Corrosion Resistant Steels. Đorđe Blagojević. (*Zaštita Mat.*, 1958, **6**, (5), 200–202). [In Serbocroat]. The composition, structure, properties and applications of heat and corrosion resistant steels are discussed, the latter particularly with reference to their uses in the food industry.—F. F.

Economical Austenitic Stainless Steels. K. Hýbek, J. Šolc and M. Zezulová. (*Hutník*, 1958, **8**, (5), 146–148). [In Czech]. The various types of stainless steels containing little or no Ni are discussed. The properties of a steel containing 0·1%C, 18%Cr, 8–9% Mn, 3·5–4·5%Ni and 0·2–0·3%N, as used in Czechoslovakia, are discussed. The granulometry of the nitrogenous ferrochrome or ferromanganese affects the final nitrogen content; these additions are best used as powders. The steel is virtually equivalent to the usual 18/8 type in all respects.—F. F.

New French Iron and Steel Research Centre. (*Met. Treatment*, 1958, **25**, June, 254–257). An account of the Maizières-lès-Metz station with notes on current researches.

METALLOGRAPHY

Microscope for Nuclear Metallurgy. (*Atomics Nucl. Eng.*, 1958, **9**, Jan., 20–21, 34). The Reichert-Shandon remote control microscope is described.

The Present State and Prospects of the Electron-Diffraction Method of Investigating Materials. Z. G. Pinsker. (*Zavods. Lab.*, 1958, **24**, (5), 597–604). The material presented in this survey of electron-diffraction methods includes some dealing with iron and molybdenum nitrides as well as with other materials.—S. K.

Electron Optics in Metallurgical Research. R. M. Fisher. (*A.I.S.I. Preprint*, 1958, pp. 39). The author describes twelve different instruments based on electron optics which are now being used in metallurgical research for detailed analysis of the morphological, chemical or crystallographic features of the microstructure of metals. Some examples of their applications are outlined.—G. F.

An Electro-Polishing Technique for the Preparation of Metal Specimens for Transmission Electron Microscopy. H. M. Tomlinson. (*Phil. Mag.*, 1958, **3**, Aug., 867–871). Iron and other metals are polished and notes on the electron-microscopical technique are given.

Revealing Microstructure in Low Carbon Steels by Electrolytic Polishing and Etching. B. S. Kasatkin. (*Zavods. Lab.*, 1958, (7), 842–843). The broad features of this method of electrolytic polishing and etching are explained, Sub-grain boundaries are revealed. The electrolyte is a mixture of 5%HCl and glacial acetic acid, with a current of 100 V and a density of 0·015 amp per cm² for 2–3 seconds. The cathode is of stainless steel. For etching: a methyl alcoholic solution of iron chloride (0·5%) and HCl (1·0%) with a 16–20 V current of 0·15–0·20 amp/cm² density for 3–6 seconds. The cathode is of stainless steel.—L. H.

Investigation of the Microscopical Non-Homogeneity of Silicon Steel by Surface Oxidation. F. K. Tkachenko and V. F. Zubarev. (*Zavods. Lab.*, 1958, (7), 837). A method is described which discloses the microscopical non-homogeneity of the silicon distribution. In silicon steels and irons, Si shows a tendency to direct dendritic segregation. The opinion, which has lately gained ground that this may be due to an inverse segregation does not correspond to the facts. Some coloured plates demonstrate this contention.—L. H.

A Small Metallising Apparatus for Use in Electron Microscopy. K. Ulbert and P. Bartl. (*Chem. Listy*, 1958, **52**, (6), 1195–1196). [In Czech]. A simple table-type vacuum metallising apparatus developed by the authors is described. Heating spirals can be changed, the angle of shadowing can be controlled, and the thickness of the evaporated layer can be measured during metallizing, without the need to release the vacuum. The cost of construction is low and maintenance is easy.

A Review of Methods for Assessing Non-metallic Inclusions in Steel. T. R. Allmand. (*J.I.S.I.*, 1958, **190**, Dec., 360–373). (This issue).

Thermogravimetric Method of Analysis Used in the Isolation of Structural Components from Steels and Alloys, and the Pyrolytic Curves of Carbides. H. Tůma. (*Hutn. Listy*, 1958, **13**, (4), 315–319). [In Czech]. Carbides and other components separated from steels and alloys show characteristic weight-loss curves on heating at elevated temperatures, due to thermal decomposition, oxidation, etc. Weight-loss–temperature curves can therefore be utilized in identifying such isolates. The evaluation of such thermogravimetric curves is discussed on the basis of data actually obtained with various carbides present in steels.—P. F.

Development of Methods for Isolating Structural Constituents in Steels. W. Koch, H. Sundermann. (*J.I.S.I.*, 1958, **190**, Dec., 374–382). (This issue).

Concerning the Crystallisation and Inoculation of Cast Iron. N. B. Gel'perin. (*Lit. Proizv.*, 1958, (1), 20–21). Inoculation of cast iron with Fe–Si, Si–Ca etc., results in an increase of the temperature of the final stages of primary crystallization and in a reduction at the same time of the final period, with the transition of graphite from an oriented to an unoriented distribution and band-shaped inclusions. In contrast to these metals, Mn, Se and others are adsorbed at the boundaries of the growing graphite crystals directing their growth in an equiaxial condition (spheroidal). Under the joint action of both types of inoculation, the former contributes to the decomposition of the cementite and formation of graphite crystals, whilst the latter promotes the formation of these crystals in a spheroidal form.—L. H.

Information on "Nuclei" for Secondary Recrystallization in Si–Fe. C. G. Dunn and P. K. Koh. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 80–84). The authors have studied the effects of growth after primary recrystallization in two cold-rolled single crystals of 3·25%Si–Fe, and present microstructure, magnetic torque, and texture data before and after grain growth. The results obtained are interpreted in terms of present knowledge of grain-growth processes.—G. F.

Influence of Vibration on Metal Properties. V. A. Serkovskii. (*Lit. Proizv.*, 1958, (5), 19–21). The author discusses the theory of the influence of vibration on liquid and solidifying metal and describes some check experiments. He discusses first the forces produced in the liquid by harmonic vibrations and their influence on gas solubility and the flotation of foreign particles, and shows that other forms of contactless vibrations can be treated similarly. He considers next vibrations, which produce hydraulic shock and shows the limitations of the applicability of either form. Shock and contactless vibrations were applied to moulds during filling and solidification and their influence on filling, density, structure and mechanical properties were determined.—S. K.

Composition and Structure of the Decarburised and Intermediate Zones in Annealed Irons. K. I. Vashchenko and N. A. Golovan'. (*Lit. Proizv.*, 1958, (3), 16–20). Experimental findings show that the transition zone develops, during annealing, between the decarburized surface and the basis metal, enriched in P, Mn, Cr, Mg and other carbide-forming elements. This zone has a fringe of pearlitic appearance in the ferritic malleable irons. It makes the mechanical treatment more difficult and can cause cracks and fractures in castings owing to the reduction in the plasticity of the metal.—L. H.

Cooling Curve for Cast Iron with Spheroidal Graphite. L. Sofroni. (*Rev. Met. Bucarest*, 1958, **3**, (1), 61–79). [In German]. Experiments here described have established an appreciable difference between the cooling curves of grey cast iron and those of spheroidal cast iron. This is ascribed in the main to the variation in the graphitization process of these two kinds of cast iron.—L. H.

Diagram of Eutectic Transformation of Cast Iron. K. P. Bunin. (*Metallov. Obra. Met.*, 1957, (1), 17–23). The diagram of eutectic transformation of iron separately takes into account the beginning of the formation of all three possible eutectic phases: graphite, austenite and cementite and also the graphitization of cementite and reflects all phase changes produced during the cooling of grey, mottled and white irons.—R. S.

The Effect of Magnesium on the Graphitization of White Cast Iron. A. V. Chernovol and Yu. N. Taran. (*Metallov. Obra Met.*, 1958, (4), 49–51). Irons with 3%C, 0·52% Si, 0·32Mn, 0·021–0·002%S, 0·09%P and 0·018, 0·047, 0·076, 0·093Mg were melted and cast in sand moulds with insulated risers and the specimens were graphitized at 1050°, 950° and 850° C, in iron crucibles in a mixture of graphite and iron chips. The course of graphite formation was observed and kinetic curves were constructed. The results do not suggest either graphite formation from unstable carbides or a great reduction in the rate of graphitization in presence of Mg.

Calculation of the Limiting Factor in the Graphitization Process. M. A. Krishtal. (*Lit. Proizv.*, 1958, (5), 22–24). The author discusses and makes use of published work on the determination of the rate-controlling factor in the graphitization of malleable iron. He points out deficiencies in the treatment in some of the work and compares measured values of graphitization parameters with those calculated from various equations. He concludes that in dense Fe–C–Si alloys of the compositions studied, the rate of the first stage of graphitization is controlled by the rate of diffusion of vacancies in the austenite towards growing graphite inclusions; in other irons, especially alloyed ones, the rate may depend also on plastic flow of the matrix, carbon diffusion and carbide solution.—S. K.

Nucleation of Solid-State Transformations. M. Cohen. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr., 171–183). The author discusses the differences between the operational and theoretical concepts of nucleation, referring particularly to the case of martensitic reactions. The athermal and isothermal nucleation of these reactions are considered, and the nature of the embryo is discussed. (46 references).—G. F.

Effects of the Proeutectoid Ferrite Reaction on the Formation of Pearlite. H. I. Aaronson. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr., 212–218). The author has investigated the processes through which pro-eutectoid ferrite can reduce the rate of formation of pearlite, and discusses the effects qualitatively in terms of heterogeneous nucleation theory. The effects of austenite grain size on the competition between the ferrite and pearlite reactions are also considered.—G. F.

Contributions to the Study of the Gamma–Alpha Transformation without Diffusion in Fe–C Alloys. B. Rotenstein, S. Caloghiru and T. Teitel. (*Rev. Met. Bucarest*, 1958, **3**, (1), 99–108). The alloys suitable for these researches must not contain carbide-forming elements of low solubility in the gamma phase, must have a relatively long stability period and must have a sufficiently high critical point for the γ–α transformation. The quantitative variation of the α-phase formed without diffusion as a function of time is given. The initial high rate of transformation decreases with time and this results in an increase in the quantity of the α-phase.—L. H.

The Kinetics of Bainite Formation in a Plain Carbon Steel. P. Vasudevan, L. W. Graham and H. J. Axon. (*J.I.S.I.*, 1958, **190**, Dec., 386–391). (This issue).

Transformations in the Solid State of the Iron–Chromium–Nickel System. II. A. T. Grigor'ev and A. Bondar'. (*Izvestiya Sektora Fiziko-Khimicheskogo Analiya*, 1954, **25**, 94–116). This report covers investigations regarding the heat treatment of the alloys at 100° intervals between 1200 and 600°, the specific electrical resistance of tempered alloys measured on specimens in the form of small rods, Vickers hardness, microhardness and differential curves of heating. The range of alloys included chromium from 3–55% and nickel from 2–20%. The phases present were: 3-single phase regions α, γ- and σ-; 4-two-phase regions $\alpha + \gamma$; $\gamma + \sigma$ and two regions of $\alpha + \sigma$; 2 Three-phase regions of $\alpha + \gamma + \sigma$.—L. H.

Influence of Grain Size on the Transformation in Austenitic Steel of Type (25–20) in Welded Seams. B. I. Medovar and Yu. B. Malevskii. (*Avtom. Svarka*, 1957, (6), 35–41). Steel catalogue index Kh23N18 is of composition C, 0·11; Si, 0·36; Mn, 0·80 Cr, 22·4; Ni, 18·2; S, 0·016; P, 0·03%. Welded seams of this steel become coarser in consequence of the transformation. In working out measures for preventing heat cracks, account must be taken of the influence of grain size due to this transformation.—L. H.

The Martensite Phase Change in Metals. M. A. Jaswon. (*Research*, 1958, **11**, Aug., 315–323). The crystal structure of martensite and the changes in the austenite–martensite transformation in Co, Li and Na are reviewed. Mechanism in terms of slip is indicated.

Shock-Induced Martensitic Transformation. R. E. Cech and D. Turnbull. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 395–397). Vibration-induced martensitic formation at low temperatures was obtained by isothermal transformation down to −196° C. An iron alloy containing 28·6 atom %Ni was powdered to particles 10–20 microns in diameter; maximum susceptibility to transformation was observed in the temperature range −140 to −160° C.

Thermal Spectra and Their Use as a New Method of Investigation, with Examples Referring to Iron and to Some Steels. M. Bolgiu. (*Studii si Cercetari de Metalurgie*, 1957, **2**, (4), 415–425). The author claims, as a result of her investigations based on these new methods now in course of development, that some phenomena so far obscure can now be explained, that allotropic and polymorphic transformations in the lattice can now be detected, as can transformations of an atomic character, and that other fields can be defined in which fresh data regarding physical and mechanical properties are to be expected.

Concerning the Composition Diagram Fe–Fe_3C as Proposed by F. K. Tkachenko and V. F. Zubarev. K. P. Bunin. (*Lit. Proizv.*, 1958, (3), 27). This composition diagram was suggested in this journal (11) 1957. The writer of this article, after experimental investigations, claims that the diagram is not reliable from the thermodynamic point of view.—L. H.

On the Position of the Equilibrium Line on the Right Side of the Fe–C Diagram. V. F. Zubarev and F. K. Tkachenko. (*Lit. Proizv.*, 1958, (3) 28). This is the reply to the preceding abstract, in which the original authors maintain their assertions and suggest that the carbon concentration as given by Bunin, consists in reality of two phases Fe_xC and Fe_3C, thus vitiating Bunin's findings.—L. H.

On the Structure and Magnetic Properties of Some Alloys of the System Fe–C–Al. N. Geru, P. Iliescu, A. Mocianu and E. Crucianu. (*Studii si Cercetari de Metalurgie*, 1957, **2**, (4), 397–413). The microstructure of alloys in this system changes with its Al content so that the degree of pearlite dispersion increases with increase in Al content up to 6–7%. Beyond this percentage, the spheroidal ϵ-phase appears. The increase of Al in solid solution lowers the Curie point to 600°. Investigations are also described regarding the changes of the cementite, the transformation austenite–cementite–pearlite, changes in the ϵ-phase and in magnetic properties.—L. H.

On the Solubility of Iron in Magnesium. K. Anderko, A. S. Yamamoto, and W. Rostoker. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 85). From the difference between chemical and magnetic iron analyses, the authors estimate that the solid solubility of iron in magnesium is of the order of 0·001% by weight.—G. F.

Studies on the Metallurgy of Silicon–Iron: 1.—Silicon Nitrides. 2.–Anomaly in the Alpha Solid Solution. A. U. Seybolt. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Apr., 161–167). The author has investigated the pressure-temperature relationships required to maintain the existence of Si_3N_4 in silicon–iron containing 0·44–11·7%Si. The critical data obtained indicate the presence of an order-disorder two-phase field extending at 800° C from about 1% to 5·5%Si, hitherto considered to be homogeneous alpha solid solution.—G. F.

The Composition-Properties Diagram of the Iron–Nickel System. I. I. Kornilov and O. Panasyuk. (*Izvestiya Sektora Fiziko-Khimicheskogo Analiya*, 1956, **27**, 164–170). The boundary of the distribution of α-solid solution in the Fe–Ni system at room temperature appears only at rupture according to the composition-reduction diagram of the cross-sectional area. This corresponds to a nickel content of 7–8%. The investigations extended further to the boundary of the two-phase regions $\alpha + \gamma$ and to the γ-solid solution; the yield point, relative elongation and reduction of cross section and formation of Ni_3Fe.—L. H.

Investigation of the System Fe-Si in the Region of the $FeSi_2$ Compound. N. Kh. Abrikosov. (*Izvestiya Sektora Fiziko-Khimicheskogo Analiza*, 1956, **27**, 157–163). These investigations considered the transformations in the solid solutions in the system in the region of $FeSi_2$ and the composition diagram for that region. $FeSi_2$ has been found subject to polymorphous transformation between 975° and 960°. The upper limit of this transformation corresponds to the leboite phase and the lower limit is near the stoichiometric constitution of $FeSi_2$.—L. H.

CORROSION

The Corrosion Mechanism of Metals under Thin Layers of Electrolytes. I. L. Rosenfel'd and T. I. Pavlutskaya. (*Zhur. Fiz. Khim.*, 1957, **31**, (2), 328–339). The experiments determined the distribution of potential and current density under thin layers of electrolytes (70–165μ). Any change of potential at the surface is observed at the cathode and the overall corrosion current is less under thin films than within the electrolyte. However, the density at the surface of contact is greater for thin films. This is explained by an increase in the cathodic process due to the regenerating oxygen. A method of calculation has been worked out based on the relation between ohmic and polarization resistance which shows that an ohmic drop in potential of approximately 4–6% from the original potential difference between the electrodes separated by 0·25 mm exists in the thin layers (70–165μ) of 0·1 N solution of NaCl and Na_2SO_4 and even in distilled water.

On the Corrosion of Metals by Uranyl Salt Solution Using ^{60}Co. G. Shinoda and T. Sano. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1957, **7**, Oct. 365–378). [In English]. Corrosion of stainless steel is described. The process resembles over-passivation in HNO_3.

Intercrystalline Corrosion of Weld Seams on Steel 1Kh18N9T in Service at High Temperatures. Kh. I. Cheskis and S. I. Vol'fson. (*Avtom. Svarka*, 1958, (5), 18–24). The composition of the steel was: ± 0·14%C; 17–20%Cr; 8–11%Ni; ± 0·8%Ti; ± 2·0% Mn. Welds made with two types of electrodes do not show the tendency to intercrystalline corrosion after welding, quenching and tempering for 2 hours at 650°. A prolonged heating from 100 to 5000 hours, between 500 and 600° develops such a tendency, but at temperatures above 650° the tendency to intercrystalline corrosion diminishes and then disappears altogether.—L. H.

Corrosion of Zinc Plated Steel. R. H. Wolff. (*Met. Fin.*, 1958, **56**, June, 46–52). Exposure to 20% salt spray fog and outdoor exposure tests are reported on panels with and without a chromate dip. Weight changes and visual inspection were used. The chromate dipped sheets required double the time of the untreated panels to show indications of rust and their appearance was always better.

Special Types of Corrosion Occurring in Welds of Stainless and Heat Resistant Steels. J. Němec. (*Zváranie*, 1958, **7**, (7), 193–196). [In Czech]. Corrosion of welds in stabilized 18/8 and other steels is discussed. The various causes of "knife-edge" corrosion, stress corrosion, corrosion at high temperatures induced by slag particles, etc. are considered.

Resistance to Corrosion of Welds of Steel Quality 23 K. N. A. Langer, O. O. Rozenberg, L. E. Vesker and L. N. Yagupol'skaya. (*Avtom. Svarka*, 1958, (3) 35–41). Experimental results show that resistance to corrosion is greater in welds made with coated electrodes than in multiple layer welds. Rupture of the welds under the conditions of the tests is of a crystalline nature and originates at the line of fusion.—L. H.

Corrosion Resistance of Cast Iron, Diffusion-Coated with Aluminium, to Molten Caustic Soda. S. Veda. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 67–71). Comparative tests were carried out to investigate the resistance of Al diffusion-coated cast iron to attack by molten NaOH. It was found that, while resistance was at first unsatisfactory, it improved considerably after a few heats had been made in the pot.

Corrosion Resistance of Materials. A. Zapletálek. (*Zváranie*, 1958, **7**, (4), 102–103). [In Slovak]. Physical, chemical and metallurgical aspects of electrolytic corrosion, corrosion fatigue, and stress corrosion are surveyed, with emphasis on carbon and alloy steels used in the chemical industry. The high corrosion resistance of plastics indicates considerable promise for their use in place of metals or in combination with metals, particularly in applications where strength is not a primary consideration.—P. F.

Corrosion Resistance of 1Kh18N9T (18/8 Cr Ni) Steel. E. I. Astrov. (*Metallov. Obra. Met.*, 1957, (1), 30–34). The amount of ferrite does not markedly affect the resistance of stainless steel to intergranular corrosion. This property is mainly influenced by the Ti/C ratio (the higher this ratio, the greater the resistance). Severely localized ferrite segregation intensifies corrosion.—R. S.

Electrochemical Measurement of Oxide Formation. D. G. Hill, B. Porter and A. S. Gillespie, jun. (*J. Electrochem. Soc.*, 1958, **105**, July, 408–412). Measurements were made of the potential between an oxide-covered wire and a Pt wire over which air or O_2 was passed in a eutectic mixture of lithium and potassium sulphates containing CaO between 550°–750° C. Iron appeared to form FeO.

On the Influence of Light on the Kinetics of Corrosion Processes. I. Sekerka, K. Smrček, E. Beránek and J. Vorlíček. (*Chem. Listy*, 1958, **52**, (7), 1218–1221). [In Czech]. It was found that light accelerates the corrosion rate in cases where no insoluble surface films are formed. The acceleration is due to the ability of photons to assist anodic and cathodic reactions. The light energy affects the rate of the reaction but not its mechanism.

Special Features of Anode Activation of Chromium and Chromium Steels. A. M. Sukhotin and E. I. Antonovskaya. (*Zhur. Fiz. Khim.*, 1957, **31**, (7), 1521–1531). Anodic polarising curves were constructed. The specimen, as anode, was placed in a 30 ml vessel in a narrow tube which communicated with the cathode space. The latter consisted of a platinum wire. In the zone of high anode potential the ratio of chromium to iron is different from that existing on the specimen. The chromium content on the surface of the specimen is impoverished. With anodic solution at negative potentials, only Fe^{++} ions pass into solution and the surface of the specimen is enriched in chromium.—L. H.

On the Passivation of Iron in Acid Solutions. A. M. Sukhotin and K. M. Kartashova. (*Zhur. Fiz. Khim.*, 1957, **31**, (6), 1256–1265). Natural magnetite ore or magnetite obtained in the form of a compact non-porous mass after calcining and melting chemically pure Fe_2O_3 in a quartz crucible at 1600° was used for the material of the specimens, which were ground to ~0·5 mm thickness. These were then fixed to the surfaces of glass tubes with a cement of wax and colophony. The tubes contained mercury in which an electrical conductor was introduced. Such electrodes had a resistance of less than 100 ohms. The investigation studies the nature of the reduction process leading to activation of the passive iron. It was found that the activation occurs because of the reduction of the passivation film of Fe_3O_4 to FeO and Fe.—L. H.

The Kinetics of Metal Dissolution. K. Smrček, I. Sekerka, J. Průšek, E. Beránek and J. Vorlíček. (*Chem. Listy*, 1958, **52**, (7), 1212–1217). [In Czech]. The time dependence of the rate of dissolution of metals in aqueous solutions of constant concentration of the common mineral acids and of sodium hydroxide were studied under conditions in which there is no formation of insoluble surface films. The rate of dissolution was found to be a reaction of zero order. The temperature dependence of the dissolution rate was determined, and an empirical relation showing the effect of temperature, concentration and time on the rate was proposed and its scope discussed.—P. F.

On the Processes Determining the Kinetics of the Dissolution of Metals. I. Sekerka, K. Smrček, J. Vorlíček and E. Beránek. (*Chem. Listy.*, 1958, **52**, (7), 1206–1211). [In Czech]. The dissolution of Mg, Fe, Al and Zn, in acids and bases was studied. The rate-controlling factor, with any given acid or base, depends upon the concentration of the corrosive agent in solution. Up to 0·1N, the rate of solution is controlled by the rate of diffusion of hydrogen ions to the metal surface; above 0·5N, by the rate of the chemical reaction leading to corrosion. In the range 0·1–0·5N both process take place to a considerable extent. Activation energies for the reactions were determined for HCl, H_2SO_4, and NaOH.—P. F.

Corrosion Testing as an Engineering Auxiliary. D. J. Fishlock. (*Mech. World*, 1958,

138, Aug., 342–348). Practical tests are reviewed and the effects of preparation and pretreatment on the results obtained are indicated.

Gas Formation in the Acid Corrosion of Zinc. I. I. Zabolotnyi and A. P. Lizogub. (*Zhur. Prikl. Khim.*, 1958, **31**, (5), 730–734). The formation of hydrogen bubbles in the acid corrosion of zinc has been studied and some rules for gas formation in aqueous solutions of sulphuric and hydrochloric acids deduced.—S. K.

The Influence of Temperature on the Solution of Iron in Sulphuric Acid in the Presence of Certain Additives. I. P. Anoshchenko. (*Zhur. Fiz. Khim.*, 1957, **31**, (2), 315–320). The additions consisted of KBr and tetrabutylammonium sulphate in different concentrations. The tests were carried out at various temperatures with KBr alone and with the tetrabutylammonium sulphate, and the rate of reaction in 2N H_2SO_4 determined. Under the conditions of the experiments it has been found that on superimposing a polarizing current the electrode polarization decreases with increasing temperatures and the stationary potential is displaced towards the positive side according to the formula of A. N. Frumkin. The activation energy for the cathodic and for the general process has been determined in the presence of the additions by the S. V. Gorbachev method of electrolysis. The activation energy increases with increase in the disturbing influence of the additions.

An Electron Diffraction Study of the Surface of Stainless Steel Corroded at a High Temperature. T. Nakayama. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 77–80). The surface layers of 13%Cr and 18–8 stainless steels heated to 700° C in an atmosphere of NH_3 containing a small amount of air were examined by electron diffraction methods. It was verified that iron nitrides and spinel-type oxides were formed on the surface of 13%Cr steel, and that CrN crystals are produced within the surface layer. No CrN is formed in the case of 18–8 steel, but Ni layers or Ni-rich γ-phase layers were detected within the oxide film. These Ni layers are considered to retard penetration of NH_3.

Steam Treating Cast Iron for Corrosion Resistance. (*Mod. Castings*, 1958, **33**, June, 43). Steam treatment followed by a dip in an oil or wax base rust-preventative is highly effective in increasing corrosion resistance and can often replace more costly processes such as Cd plating.—A. G.

Zirconium and Titanium Inhibit Corrosion and Mass Transfer of Steels by Liquid Heavy Metals. O. F. Kammerer, J. R. Weeks, J. Sadofsky, W. E. Miller, and D. H. Gurinsky. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 20–25). The authors have studied the mechanism by which Zr and Ti inhibit solution mass transfer of steels by liquid Bi, Hg and Pb. Bismuth and mercury adsorb on the surface of the steels and react with nitrogen and possibly carbon in the steels to form inert, adherent surface layers. These inhibitors decrease the solution rate of iron into bismuth, and require a higher supersaturation for precipitation of iron from bismuth.—G. F.

Cathodic Protection of Steel in Salt Water. W. J. Schwerdtfeger. (*N.B.S. Techn. Bull.*, 1958, **42**, May, 83–84). In 3%NaCl in tap water the best degree of protection was obtained at −0·77V (ref. standard calomel).

Control of Corrosion by Cathodic Protection. B. N. Dey. (*Sci. Eng.*, 1958, **11**, May-June, 51–54). Instances from Indian experience are briefly noted. The paper was read at the Moscow Conference in May.

Cathodic Protection of Buried Structures. Joint Committee for the Co-ordination of the Cathodic Protection of Buried Structures. (*Pamphlet*, 1957, Dec., pp. 31). Principles are summarized and practical methods of cathodic protection by sacrificial anode and impressed current are outlined. A practical procedure for the survey of any underground system is set out. Interference currents and their effects are then reviewed and methods for their reduction are listed. Research topics at present being pursued are mentioned and a short glossary is added. (35 references).

Cathodic Protection in Refrigerating Plant. L. Piatti and H. Bourquin. (*Sulzer Tech. Rev.*, 1957, **39**, (4). 31–37).

ANALYSIS

Improved Vacuum-Fusion Method for the Determination of Oxygen and Nitrogen in Metals. N. A. Gokcen. (*Trans. Met. Soc. A.I.M.M.E.*, 1958, **212**, Feb., 93–100). The author describes the construction and operation of a simple and accurate vacuum-fusion apparatus. Repeated analyses of the Bureau of Standards samples show that they are inadequate for the acceptable range of oxygen. The limits of interference of Mn, Al and Ti are established, and the effects of tin and water-cooling of the furnace tube are discussed.

Sampling of Liquid Steel for Hydrogen. J. G. Bassett, J. W. Dougherty and G. R. Fitterer. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 44–52)). The authors describe existing techniques for sampling liquid steel for H_2 determination, and give the results of trials comparing methods of taking the sample from a spoon with methods of sampling the bath direct. It is concluded that in all methods there is a danger of H_2 loss during sampling. The design of a new furnace immersion sampling device which overcomes this disadvantage is outlined.—G. F.

The Determination of Hydrogen in Steel by a Carrier-gas Technique. C. E. A. Shanahan and F. Cooke (*J.I.S.I.*, 1958, **190**, Dec., 381–385). (This issue).

Colorimetric Determination of Iron with 2 : 2′-Dipyridyl. M. Grat-Cabanac. (*Anal. Chim. Acta.*, 1958, **19**, July, 108). It is shown that Co, Ni and Mn do not interfere.

The Determination of the Surface Lead and Cadmium Contamination on Stainless Steel Tubing (Polarographic Method). F. Elliott. (*U.K. Atomic Energy Authority Industrial Group. IGO-AM/W-94*, 1957, pp. 5). Degreased tubing is extracted with 1·6M HNO_3, the washings fumed with $HClO_4$, reduced with N_2H_4 and polarographed.

Chromatographic Separation of Cobalt and Nickel in Ore and Alloy Analysis. D. I. Ryabchikov and L. V. Borisova. (*Zhur. Anal. Khim.*, 1958, **13**, (3), 340–343). Anion exchange gives more rapid separation of Co and Ni than does cation exchange. Many types of anion exchange material have therefore lately been synthesized. A very suitable anion exchange material is EDE-10, a condensation product of ethylenediamine and epichlorhydrin and anion exchange material AN-2F which is a condensation product of polyethylenediamine with phenol and formaldehyde. With radioactive isotopes ^{60}Co and ^{63}Ni this method has given good results in isolating Co and Ni from ores and alloys.

The Gravimetric Determination of Tungsten in the Presence of Molybdenum. A. Claeys. (*Anal. Chim. Acta*, 1958, **19**, Aug., 114–118). The use of β-naphthoquinoline is described.

The Separation of Niobium, Tantalum and Titanium in Ferrotantaloniobium. E. Lassner and R. Scharf. (*Zeits. Anal. Chemie*, 1958, **160**, (1), 21–22, reprint). EDTA is used as masking agent in precipitating Nb, Ta and Ti with NH_3. Glycerol and boric acid improve filterability which prevents the interference by fluoride.

Activation Analysis of Vanadium in High Alloy Steels Using Manganese as Internal Standard. G. Leliaert, J. Hoste and J. Eeckhaut. (*Anal. Chim. Acta*, 1958, **19**, July, 100–107). Pile activation is employed.

Separation of Niobium and Tantalum with Cupferron. A. K. Majumdar and J. B. Ray Chowdhury. (*Anal. Chim. Acta*, 1958, **19**, July, 18–22). Analysis of stainless steel is included. The use of tin salts for coprecipitation gives good results in presence of complexone III.

Separation of Niobium and Tantalum with *N*-Benzoyl-*N*-Phenylhydroxylamine. A. K. Majumdar and A. K. Mukherjee. (*Anal. Chim. Acta*, 1958, **19**, July, 23–26). Ti, Zr, vanadate and molybdate interfere with niobium determination.

Determination with Ammonium Benzene- and Naphthalenesoleninates. I. P. Alimarin and V. S. Sotnikov. (*Zhurn. Anal. Khim.*, 1958, **13**, (3), 332–335). A method is described for determining Zr and for its separation from various elements. The reagents C_6H_5-SeO_3NH_4 and $C_{10}H_7$-SeO_3NH_4 in strong acid solutions form white amorphous precipitates, which after calcination yield ZrO_2. This is weighed quantitatively, and with an initial content of 2–10%Zr the error does not exceed ± 0·01%.—L. H.

Analysis of Microquantities of Antimony, Tin and Arsenic in Ferrotungsten. H. Goto, Y. Kakita and M. Sase. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1958, **10A**, June, 207–211). Photometric determination after separation as sulphides is described.

Separation of Uranium, Vanadium and Iron by Chromatography on Paper. Yu. V. Morachevskii, M. N. Gordeeva and T. E. Kruglova. (*Zavods. Lab.*, 1958, (7), 790–793). With a circular chromatogram, using a mixture of glacial acetic acid and nitric acid (95 : 5) as a mobile solvent, it is possible quantitatively to separate uranium, vanadium and iron from mixtures containing these elements in a wide range of proportions with a margin of error between 2 and 11%.—L. H.

Standard Samples of High-Temperature Alloys. (*N.B.S. Tech. Bull.*, 1958, **42**, July, 138). Compositions of stainless steels available are given.

Gas Chromatography and Some Related Methods. Consolidated Electrodynamics Corp. (*Pamphlet*, 1956, pp. 68). A bibliography.

New Two-Arc Generator for Spectrochemical Analysis. Khuan Bun-Li. (*Zavods. Lab.*, 1958, (3), 348–352). A description and a diagrammatic circuit is given of an instrument with which experiments are described on spectral analysis. It was found possible to superimpose the Ca1 line 3344·5 Å on the Zn1 line 3345·0 Å if the calcium concentration exceeded 10%.—L. H.

Application of the Spectrographic Laboratory to Production Control. K. P. Campbell. (*A.I.M.M.E., Proc. O.H. Comm.*, 1956, **39**, 235–239). The spectrographic laboratory of Sheffield Steel Div. of Armco Steel Corp. houses a direct-reading spectrograph and an emission spectrograph. Details of the two instruments and of their specific applications in production control are given. Savings have been realized in manpower, materials, and production time because of the accuracy and rapidity of the equipment.—G. F.

Spectral Analysis of Metals. Passereau. (*Microtenic*, 1958, **12**, April, 64–68). A general account with a description of the Huet spectrograph UV120 for high-alloy steels.

Spectrographic Determination of Hydrogen in Some Metallic Alloys and in Weld Seams. E. S. Kudelya and O. P. Ryabushko. (*Avtom. Svarka*, 1958, (5), 12–17). A method is described for determining H_2 in titanium alloys, chromium–nickel steels and weld seams. The sensitivity of this method for H_2 in steel is approximately 20 times greater than in titanium alloys.—L. H.

Mass Spectrometric Determination of Gases in Cast Iron. E. Kato. (*Waseda Univ. Rep. Castings Res. Lab.*, 1957, (8), 81–84). A description is given of the construction of a vacuum furnace connected to a mass spectrometer, and its use for determining gas content in cast iron. In determining nitrogen, it was found that most of the nitrogen was extracted at 1350° C, complete removal being obtained at 1650° C. Results compared well with chemical values.

A Spectrophotometric Method for the Determination of Nickel. L. D. Brake, W. M. McNabb and J. F. Hazel. (*Anal. Chim. Acta*, 1958, **19**, July, 39–42). EDTA is used as reagent.

Radioisotopes and Their Uses in Metallurgy. F. Scott. (*Met. Treatment*, 1958, **25**, June, 227–232). A generes account of radioactivity, production of isotopes, methods of detection of radiation and uses in steel production and in analysis is briefly sketched.

INDUSTRIAL USES AND APPLICATIONS

Steel in Prestressed Concrete. W. O. Everling. (*A.I.S.I. Preprint*, 1958, pp. 20). The

author discusses the desirable properties of steel wire for pre-stressed concrete, and describes the heat treatments applied to obtain them. Attention is given to the problem of stress corrosion, and some of the developments in the past 10 years are reviewed.—G. F.

Metallurgical Research. W. E. Dennis. (*Atomics Nucl. Eng.*, 1958, **9**, Jan., 7–9). The steel pressure vessels are dealt with in particular.

Steel Castings for Oil Refineries. (*B.S.F.A. publication*, [1958], pp. 14). Notes on the industry and illustrations of equipment and parts are given.

Steel Castings in Electrical Power Plant and Equipment. (*B.S.F.A. publication*, [1958], pp. 15). Notes on the industry and illustrations of castings are given.

High Strength Steels for Aircraft Applications. A. J. Lena and E. E. Reynolds. (*A.I.S.I. Preprint*, 1958, pp. 26). The authors consider the present status of high strength steels for aircraft applications. They describe recent developments in alloys for airframe construction and jet engines, considering particularly their heat treatment, and review the latest manufacturing and testing methods.

Stainless Steel and Nickel-Base Alloys for Use in Atomic Power Plants. M. A. Cordovi. (*Can. Min. J.*, 1958, **79**, July, 80). A note on a lecture given in Holland.

Steel Castings for Nuclear Power Plant. (*B.S.F.A. publication*, [1958], pp. 15). Notes on nuclear fission and illustrations of plant and castings are given.

HISTORICAL

An Experimental Investigation into Primitive Iron-smelting Technique. E. J. Wynne and R. F. Tylecote. (*J.I.S.I.*, 1958, **190**, Dec., 339–348). (This issue).

The English Steel Industry Before 1856, With Special Reference to the Development of the Yorkshire Steel Industry. M. W. Flinn and A. Birch. (*Yorkshire Bulletin*, 1954, **6**, Sept., 163–177). An account of early processes and locations, with notes on the Crowleys and Huntsman and the rise of the industry in South Yorkshire.

The Iron Bridge at Coalbrookdale. R. Maguire and P. Matthews. (*Architectural Association Journal*, 1958, **74**, July-Aug., 31–45). A reassessment of the part played in the design by T. F. Pritchard, and various historical notes with plans and illustrations.

Examination of an Early Bessemer Rail. (*J.I.S.I.*, 1958, **190**, Dec., 391–393). (This issue).

A Steel Centenary. (*Anglo-Swedish Review*, 1958, Sept., 181–184). An illustrated account of the Bessemer process in Sweden and the recent celebrations.

Forging in the Past. III. R. C. Benson. (*E.S.C. News*, 1958, **12**, Summer, 4–12). The development of the steam hammer is described and illustrated and also of the forging press. Manipulator design is then reviewed.

Buildings Cast in Iron. F. Evans. (*Brit. Steel.*, 1958, **24**, June, 178–179). A brief survey of buildings of cast iron put up in the early 19th century.

The Physical Chemistry of Steelmaking—A Tribute to Dr. C. H. Herty, jun. G. R. Fitterer. (*A.I.M.M.E., Proc. O.H. Comm.*, 1957, **40**, 281–302). The author reviews the researches carried out by Herty and his co-workers into the physical chemistry of steelmaking. Special attention is given to the determination of iron oxide in liquid steel, the deoxidation of steel with Si and with Mn–Si alloys, and the problems of slag control.

Contribution by Charles Holmes Herty, jun. to the Steel Industry. J. E. Jacobs. (*A.I.M.M.E., Proc. O.H. Comm.*, 1957, **40**, 315–318). The author briefly reviews some of the many contributions made by Herty to the steel industry. These include the development of a steelmaking practice for free-cutting steel; investigations into inclusion formation, distribution, and elimination; production and control of fine-grained steel; and the recovery of V from O.H. slags.—G. F.

ECONOMICS AND STATISTICS

Market Sampling Study on Iron and Steel Products. (*O.E.E.C. Project No.* 328, 1958, June, pp. 116). A study on the demand for steel products was made in Switzerland. Structural engineering, street lighting, rails and sleepers, metal containers, household appliances and motor vehicles and plate, sheet, bar and sections and rails and sleepers were covered for the next five years. The methods used are described and comments on them are given.

MISCELLANEOUS

Computers in the Steel Industry. (*Met. Treatment*, 1958, **25**, May, 205–208). A report of the BISRA Conference.

The Works Laboratory and the Automation of Production. (*Zavods. Lab.*, 1958, **24**, (5), 515–518). This editorial discusses the extent of automation in Soviet industry, with special reference to the iron and steel industries and the part to be played by works laboratories in extending automation.—S. K.

Cobalt and Its Alloys. A Summary of Allotropy and Phase Diagrams. F. R. Morral. (*Publication of the Cobalt Information Center*, 1958, May, pp. 125). A bibliography reproducing the appropriate equilibrium diagrams.

Cobalt in Stainless Steel. (*Cobalt Information Center, leaflet*, 1p.). **Aluminium–Cobalt Alloys**, (pp. 4). **Corrosion Bibliography on Cobalt and Cobalt Alloys.** (pp. 11). **Bibliography on Electroplating of Cobalt and Cobalt Alloys.** (pp. 16). **Cobalt in Cast Iron.** (1 p.). All the above are bibliographies in alphabetical order of authors.

Vanadium. J. Lomas. (*Can. Min. J.*, 1958, **79**, July, 90–92). A review of the occurrence and properties of the metal.

Improved Production of Vanadium from Slags. D. Trojka and K. Pálka. (*Hutn. Listy.*, 1958, **13**, (4), 371–384). [In Czech]. Properties and methods of producing V are surveyed. Experimental work of the authors dealing with the effects of various process variables on the yield obtained by the method of oxidation roasting of V slags is considered. The yield is improved (*a*) by reduction in the granulometry to the finest particle size obtainable in practice; (*b*) by the rapid cooling of the roasted charge from the roasting temperature of 820° C by means of water in order to prevent the reverse reaction; and (*c*) by the addition of about 8% of NaCl as roasting flux. Sodium carbonate and sulphate additions are less effective as roasting agents. The presence of CaO is undesirable; the less lime there is in any given slag the better is the progress of the reaction. The results obtained are embodied in 8 tables and 16 figures.—P. F.

Density of Molten Cu–Fe Sulphide Mattes. M. Bourgon, G. Derge and G. M. Pound. (*Trans. Met. Soc. A.I.M.E.*, 1958, **212**, June, 338–340). Experiments on a mixture of equal weights of Cu_2S and FeS over a temperature range from the liquidus to 1500° C showed that the density of the matte followed a roughly additive rule of mixtures, but that the temperature coefficient of density was larger than that for Cu_2S. The results are discussed.

BOOK NOTICES

ASSOCIATION OF BRITISH CHEMICAL MANUFACTURERS AND SOCIETY FOR ANALYTICAL CHEMISTRY: JOINT COMMITTEE. "*Recommended Methods for the Analysis of Trade Effluents.*" 10 × 6¼ in. pp. xii + 124. 1958, Cambridge: Heffer & Sons Ltd. (Price 42*s*).

The book may be summarized as a codification of standard methods, but is not without discussion and comparisons of procedures, and naturally is indispensible to anyone concerned in any way with effluent examination. No less than 28 pages are given to Oxygen Demand, but for the metallurgical industry the methods for metallic contaminants and for a few of the non-metallics, (cyanides, chlorides, sulphides, etc.) will be of greater interest. As always, a laboratory in control of an effluent where probable composition, at any rate qualitative, is known, would generally be able to make use of short cuts and simplified procedures, as well as *ad hoc* tests based on the particular combination of ions occurring. For any official purpose, however, methods such as these of a reliability guaranteed by the high standing of the bodies responsible, must be available for reference. The methods have appeared in the "Analyst" and the paper and printing resembles that used in that journal and is, of course, excellent.—J. G. C.

INSTITUTION OF METALLURGISTS. "*Effect of Surface on the Behaviour of Metals.*" 9¼ × 5¾ in. pp. vii + 100. Illustrated. London, 1958: Iliffe & Sons; New York; Philosophical Library. (Price 21*s*.).

This is the text of a series of lectures delivered as a refresher course in 1957 and consists of "Methods of Preparation and Examination of Surfaces," by G. J. L. Bailey; "Influence of Surface Treatments on the Chemical Behaviour of Metals", by T. P. Hoar; "Relationship between Surface Condition, Friction and Wear," by F. T. Barwell and "Influence of Surface on the Physical Properties of Metals," by R. W. B. Stephens. The scope and quality of these courses are now well known and the present series conforms to the same exacting standards although they perhaps raise many problems and deal with them rather briefly and, in some cases, would not be very illuminating without reference to the literature, for which, however, the necessary papers are specified. As refresher courses to metallurgists already familiar with the older work this is probably no disadvantage. Few topics are raised that the reader would not like to see developed further, and this is, perhaps, a merit of a publication of this kind. In the later sections especially, where the field is very wide, the amount of metallurgical interest brought out without extreme technicality and complex calculation is remarkable, though the effect is in danger of leaving the advanced worker rather in the air. As an introduction to modern theory, however, the symposium is admirable. J. G. C.

MORRIS, J. H. and L. J. WILLIAMS, "*The South Wales Coal Industry* 1841–1875." 8½ × 5½ in., pp. xii + 289. Illustrated. Cardiff, 1958: University of Wales Press (Price 25*s*.).

This is the first of two volumes, the second of which is intended to bring the story to 1914. This volume has a unity of its own, for during the period (1841–75) it covers, the value of the steam-coal resources of South Wales became apparent and the coal industry, spurred on by the transition to steam transport both at sea and on land, achieved the industrial predominance which had previously been held by the iron industry. The end of this period marked also two other major changes: the rise of the limited liability company at the expense of the individual owner or partnership and the shift of the main producing area from the Aberdare valley to the Rhondda. The authors have produced a valuable and well documented history of a generation of very rapid economic and social change. In the short space of 289 pages they have given a succinct account of many aspects of the industry, including an examination of the dwindling importance of the regional iron industry which slowly became more efficient. (Dowlais, the best Welsh practice, claimed to use the remarkable figure of 25 cwt. of coal for each ton of pig-iron in 1869—on the average 2½ tons of coal were still required in South Wales in 1874 however). Other subjects dealt with are

changes in technique, the relationship between landowners and coal-owners, the structure of the industry, financial and commercial organization and social conditions and industrial relations.—M. L. P.

"*Nuclear Power Year Book* 1958/9." Edited by W. Davidson. 8¾ × 5½ in., pp. 570. Illustrated. London, 1958: Rowse Muir Publications Ltd. (Price £2 12*s.*).

This second edition has been revised and expanded since the first publication in 1957. It is likely to prove a handy reference work and includes a "Who's Who In British Nuclear Energy," and various lists giving world authorities, national agencies, trade names and British companies with addresses and products. The main technical material occupies about a quarter of the book and comprises an Isotope Section, some short review articles and a section of twenty pages entitled "Nuclear Metals," including a brief, but useful discussion of some physical and mechanical properties of pressure vessel and heat- and corrosion-resisting steels.—M. L. P.

PFANN, W. G. "*Zone Melting*." Wiley Series on the Science and Technology of Materials. 9 × 5¾ in., pp. xvi + 236. Illustrated. New York, London, 1958: John Wiley & Sons, Inc., Chapman & Hall Ltd. (Price 60*s.*).

Zone Refining was first used to produce germanium of extreme purity and precise composition for use in the transistor. Its success was spectacular and commercial use followed quickly: since then zone melting has been applied to many other substances and has become an important technique in research and manufacture. This book, the first on the subject, includes all the information needed by either scientist or manufacturer to plan a zone melting process or to decide whether one is feasible.

Following an introduction there are chapters dealing with normal freezing and distribution co-efficient, the theory of zone refining, techniques of zone refining, applications of zone refining, continuous zone refining, zone levelling and single crystal growth, methods of perturbing the concentration, and temperature gradient zone melting; these are covered in just over 200 pages and in addition there is a useful Appendix giving 20 graphs of computed zone refining curves showing relative solute concentration as a function of distance in zone lengths for various numbers of zone passes.

It will interest many readers to know that the process has been applied to solid-solid transformation of either the eutectoid or peritectoid type and that zone melting in a constant temperature gradient differs from the normal technique in the scale of the molten zones, in the manner of moving them and usually in the amount of solute in the zones. The variety of techniques of zone refining, particularly the continuous techniques, described in Chapter 4 make fascinating reading.

Owing to the success of the zone melting technique in purifying germanium for transistors, the method has since been applied to a large number of other substances, chemicals as well as metals, and about 100 papers, dealing largely or entirely with some aspect of zone refining, have followed the basic paper which appeared in 1952. Although the transistor application finds frequent reference in the book, the author discusses at length other materials and applications, each chapter being fully referenced. The book is extremely readable and the few Americanisms, e.g. abbreviations of T.G.Z.M. for "temperature gradient zone melting" will only slightly offend the more aesthetic readers. This book is thoroughly recommended.—L. NORTHCOTT.

SALMON, WILLIAM H., and ERIC N. SIMONS. "*Foundry Practice*." With illustrations, by E. G. Gardner. 8¼ × 5½ in., pp. x + 374. Illustrated. London, 1957: Sir Isaac Pitman & Sons Ltd. (Price 32*s.* 6*d.*).

This book, first published in 1951 and re-printed last year, is already well known and widely accepted as a textbook for the intermediate foundrycraft examination of the City & Guilds of London Institute. One of the authors possesses a wealth of personal experience both in industry and the teaching of foundry technology. His co-author is a frequent writer of technical subjects who, in collaboration with other authorities, has produced several excellent textbooks on metallurgical subjects.

The student will find this book meets his full requirements and particularly useful are the test questions which follow each chapter. Skeleton answers to these questions are given in an appendix of over 40 pages and although the authors apologize in advance for them it is the reviewer's belief that they contribute much to the overall value of this book. There is also a selected bibliography on foundry practice which is well compiled and ideally suited to the needs of the thoughtful young technologist, foreman or junior manager striving for success and promotion.

The metallurgical sections are extremely well written and up to date: references to British Standards as recently as 1956 are to be found. Other chapters are not quite so modern; for example, no mention is made of the mains frequency induction furnace, plastic patterns, radiofrequency core drying or shell cores. Close reading has revealed only one small printer's error and the only minor annoyance is the too frequent use of the now overworked word "blueprint" when the authors really mean "drawing."

The book is neatly bound, well illustrated and at 32*s.* 6*d.* is thoroughly good value for money.—R. V. RILEY.

A. C. STRICKLAND (Editor). "*Reports on Progress in Physics*." Vol. 21. 10 × 7 in., pp. 383. Illustrated. London, 1958: The Physical Society.

This year the topics dealt with are "Average Energy Expenditure per Ion Pair in Gases and Gas Mixtures," by J. M. Valentine and S. C. Curran; "Absorption and Fluorescence Spectra of Ions in Crystals," by W. A. Runciman; "Electromagnetic Excitation of Nuclei by Nuclear Projectiles and Electrons," by R. Huby; "Physics of Nerve Processes," by R. Fatt; "The Theory of Collective Excitations in Nuclei," by D. M. Brink; "Fourier Methods in Structure Analysis by Electron Diffraction," by J. M. Cowley and A. L. G. Rees; "The Specific Heats of Metals at Low Temperatures," by D. H. Parkinson; "Mesonic Atoms," by D. West; and "Production and Measurement of High Temperatures," by W. Lochte-Holtgreven.

These will at once be recognized as research topics of the kind on which future progress in the sciences will be based, though which sciences it would be difficult at this stage to foresee; the observations in any field having a disconcerting way of finding their applications in quite unexpected directions. The separate articles are of the accustomed high quality, fully referenced and shirking no difficulties of description nor of mathematics, but they would be of interest only to the very specialized metallurgist even in the case of the report by Dr. Parkinson and that by Dr. Lochte-Holtgreven, the latter dealing mainly with very high temperatures indeed and mainly also of very short duration.

J. G. C.

NEW PUBLICATIONS

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Elevated Temperature Strain Gages*." S.T.P. No. 230. 9½ × 6 in., pp. iv + 163. Illustrated. Philadelphia, 1958: The Society. (Price, Members, $3.60; non-members, $4.50).

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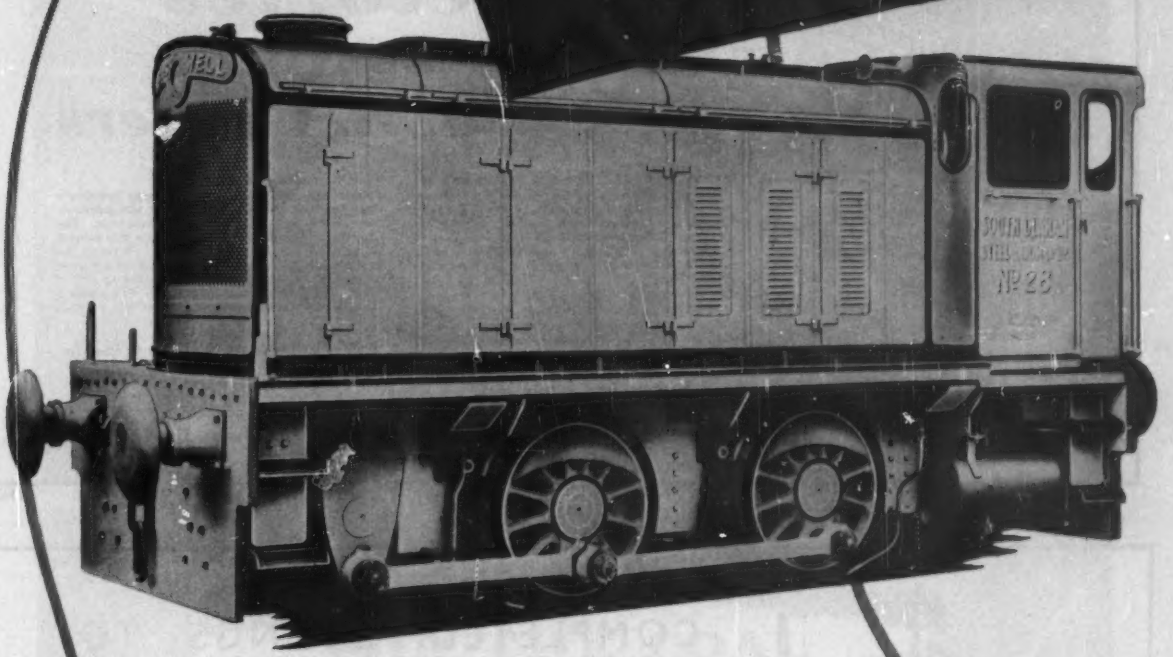

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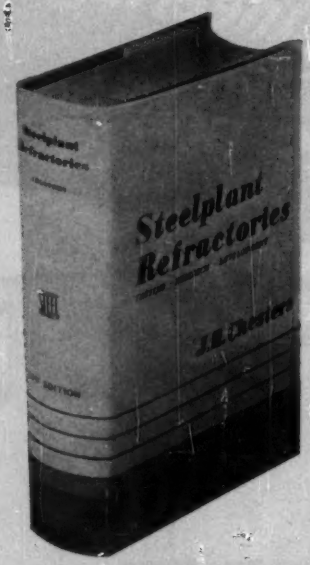

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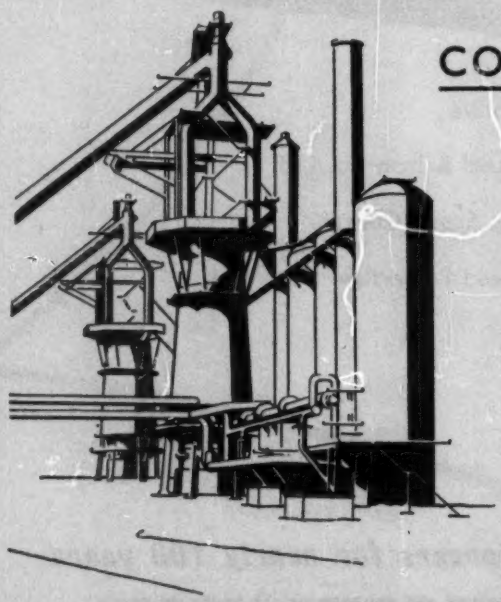

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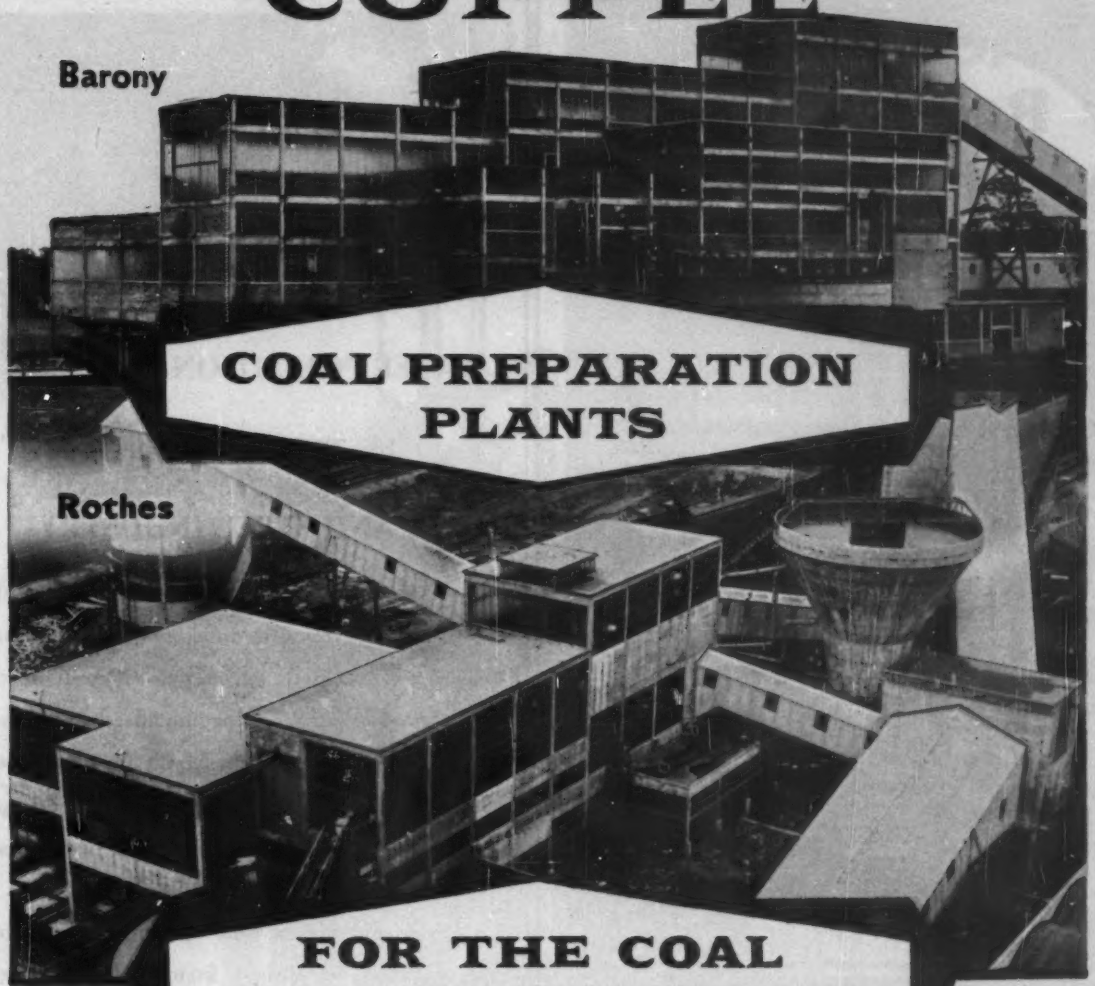

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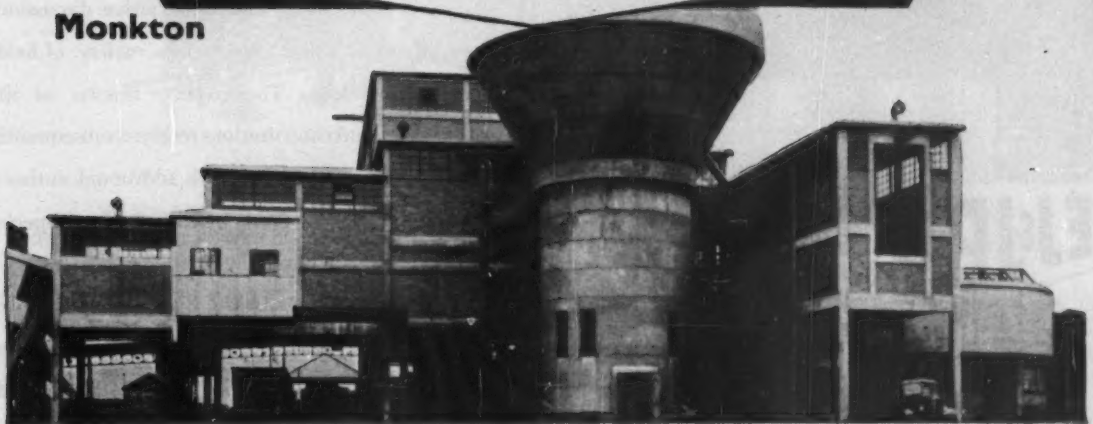

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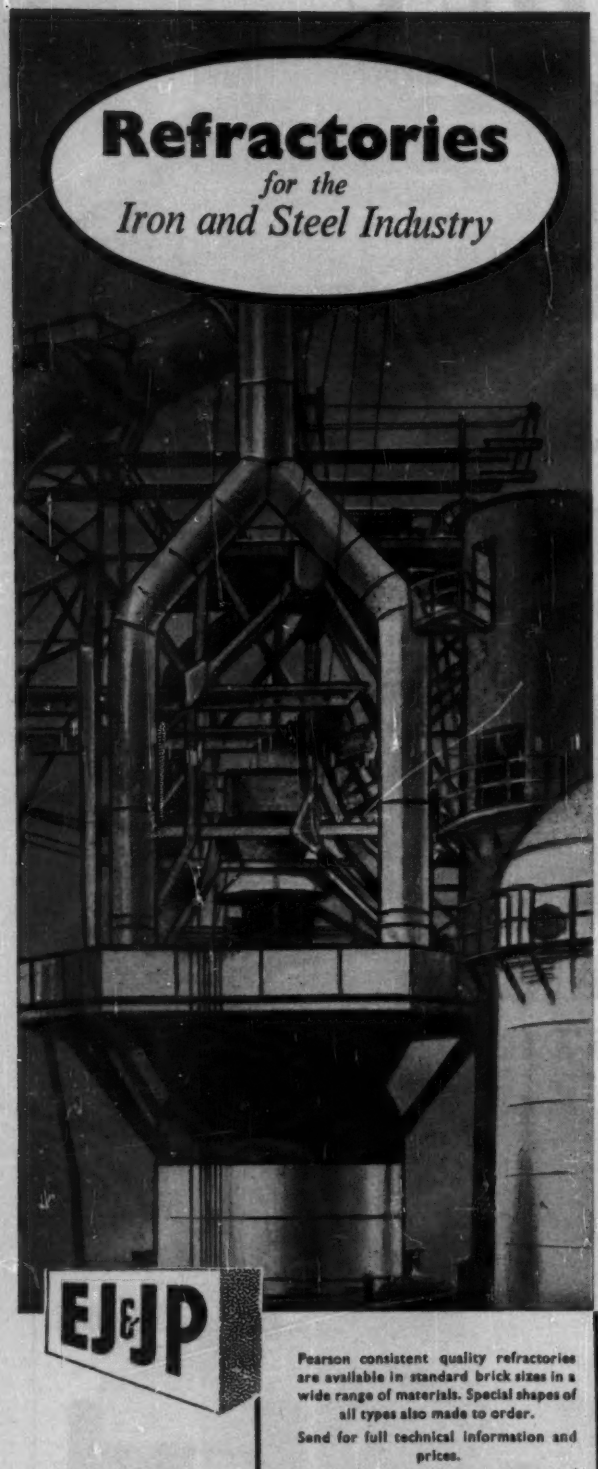

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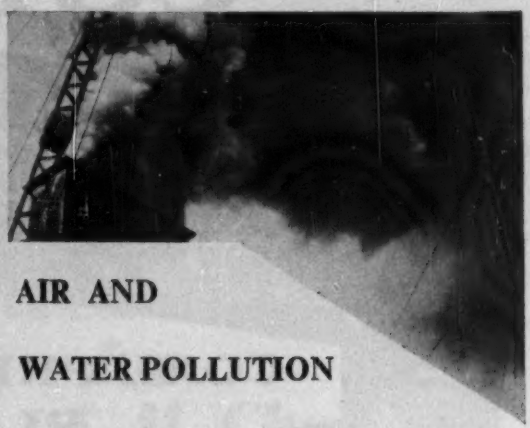

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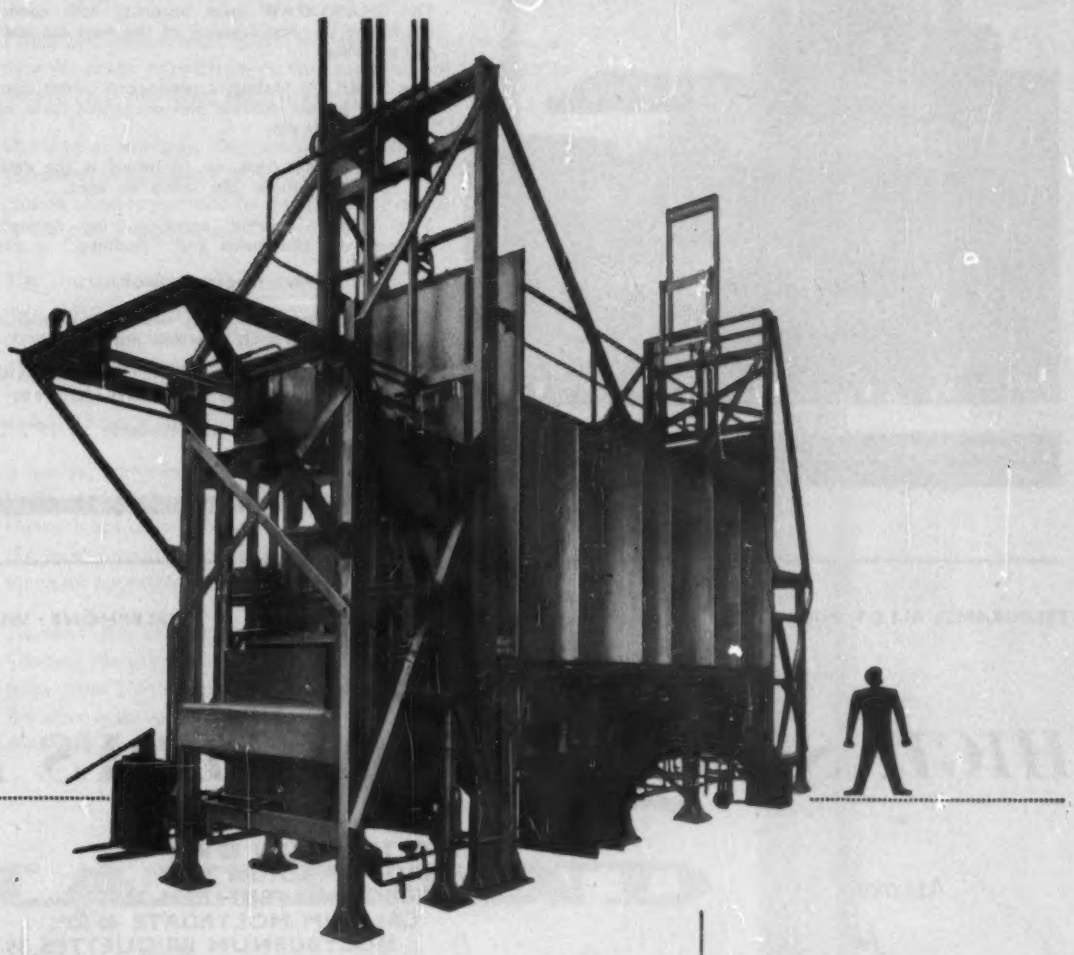

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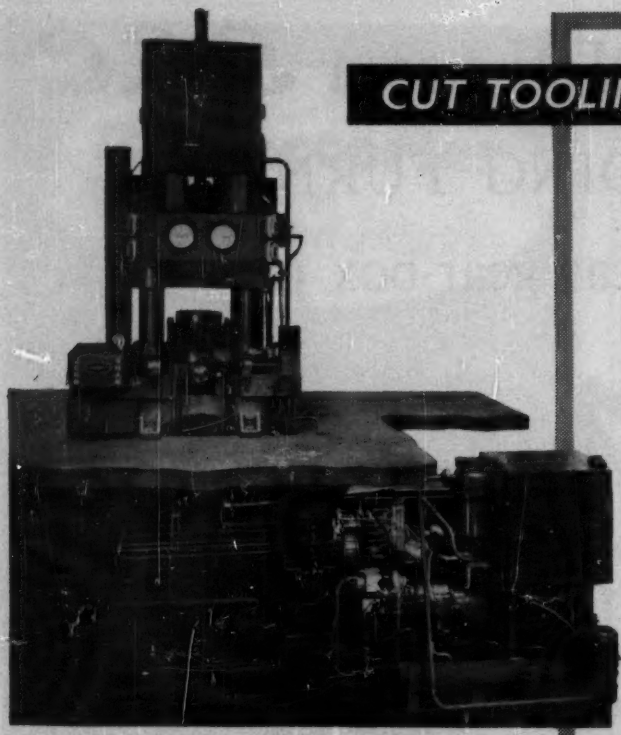

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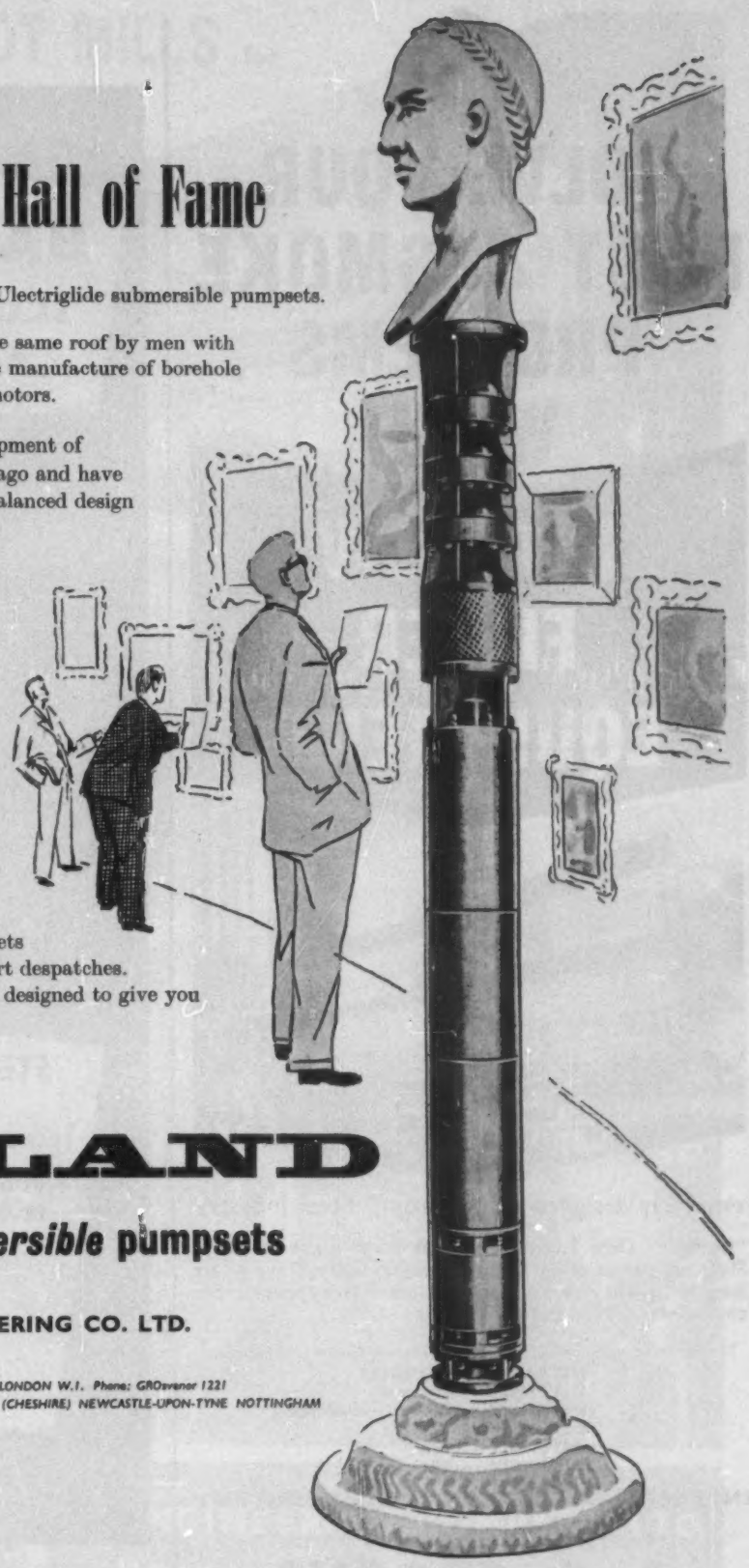

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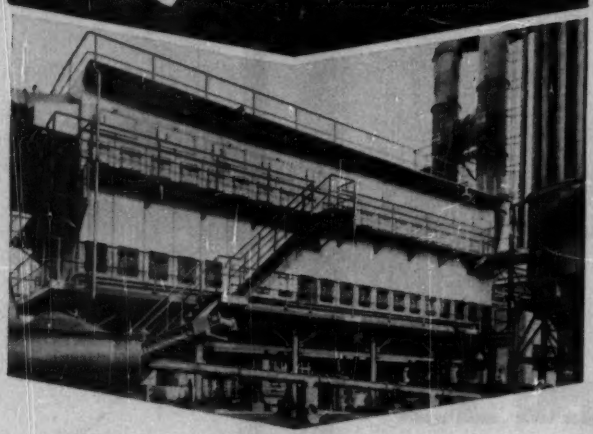

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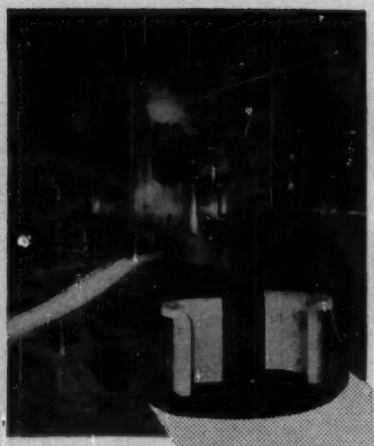

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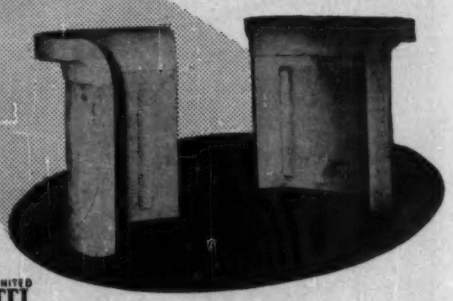

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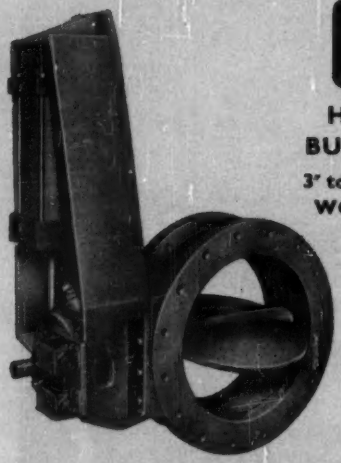

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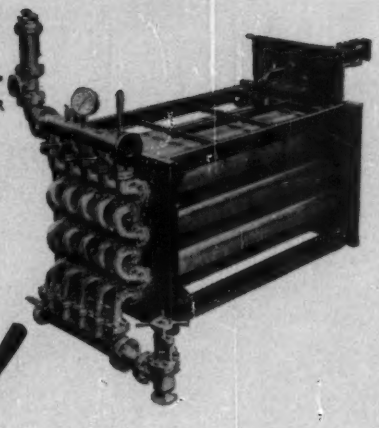

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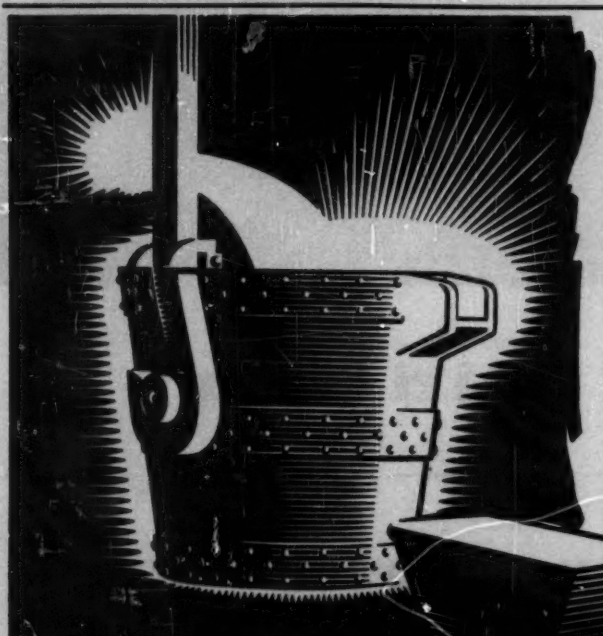

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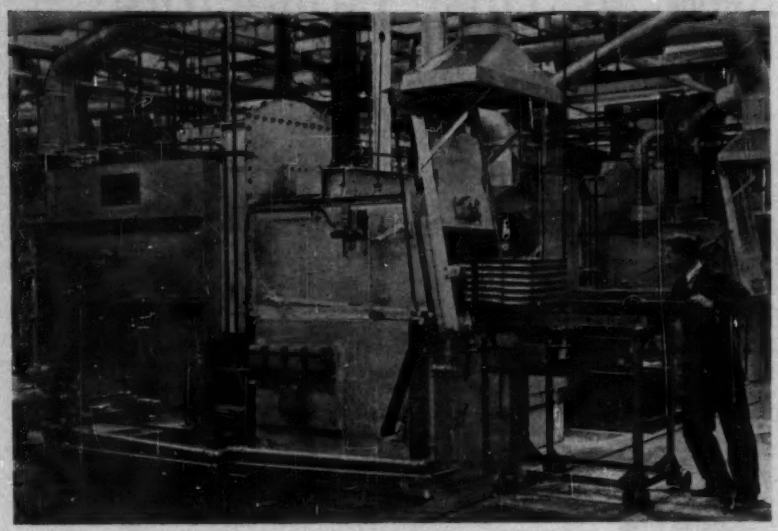

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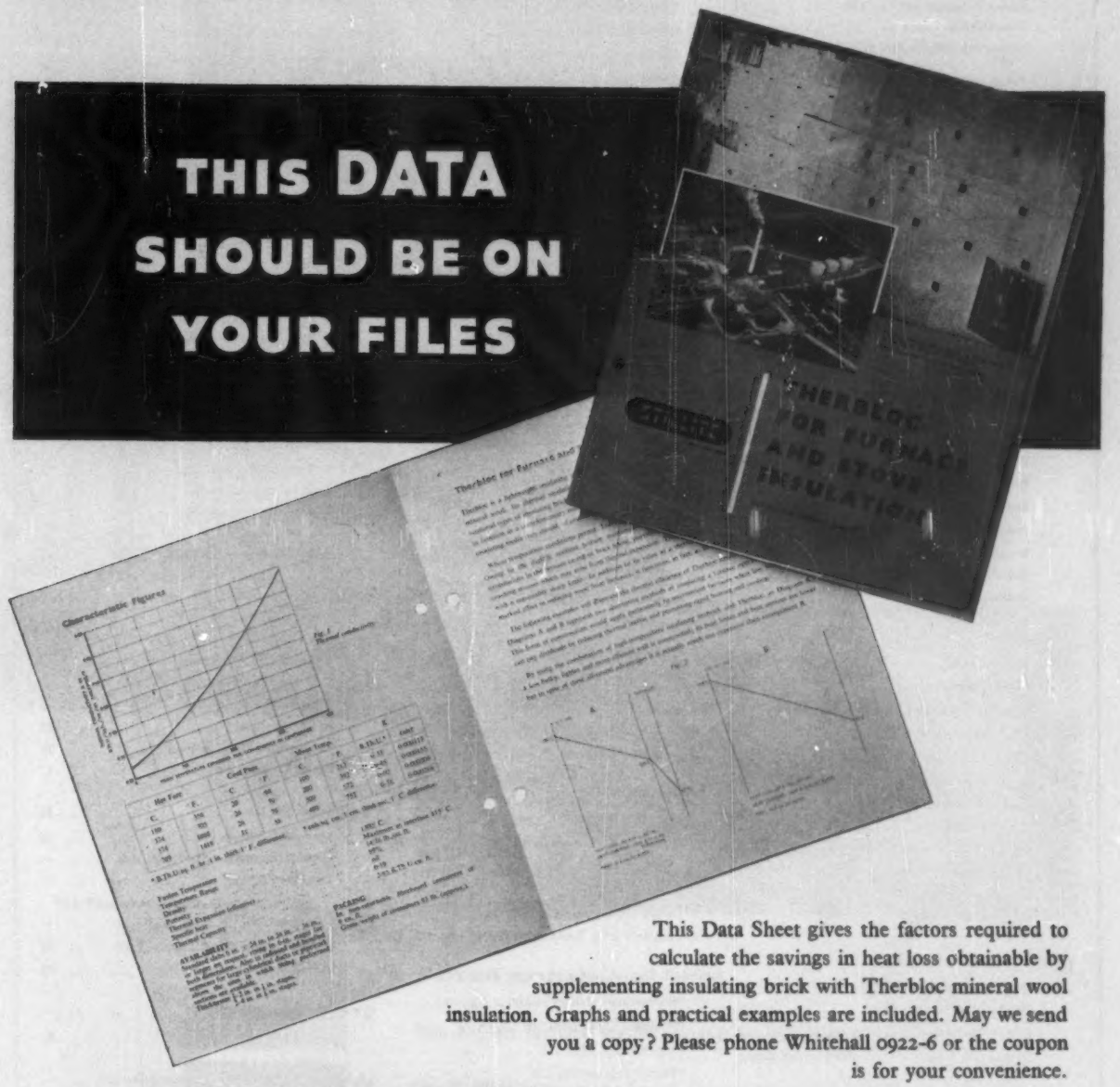

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ADDRESS.....

Index to Advertisers

Adamson-Ailiance Co. Ltd. 17
Adamson Joseph and Co., Ltd. 44
Allen West & Co., Ltd. ... ... —
Armstrong Whitworth (Metal Industries) Ltd. ... ... —
Arrol, Sir Wm., & Co., Ltd. 48
Ashmore, Benson & Co. Inside Back Cover

Bairds & Scottish Steel, Ltd. 76
Baker Platinum Division ... ... —
Beardmore, William, & Co., Ltd. ... ... —
Bigwood, Joshua, & Sons, Ltd. ... ... —
Birfield Industries Ltd. 11
Birlec, Ltd. 64
Boby, William & Co., Ltd. ... ... —
Bradley & Foster Ltd. ... ... —
Brightside Foundry & Engineering Co., Ltd., The 43
British Acheson Graphite Ltd. 57
British Electrical Development Association 27
British Furnaces, Ltd. 82
British Oxygen Gases, Ltd. ... ... —
British Paints, Ltd. ... ... —
British Rollmakers Corporation, Ltd. ... —
British Thompson-Houston Co., Ltd., The 24
British Timken, Ltd. 41
Brown Bayley Steels, Ltd. 58
Burn Fireclay Co. Ltd., The ... ... —
Bushing Co., Ltd., The 47

Carblox Ltd. ... ... —
Colvilles, Ltd. 56
Consett Iron Co., Ltd. 9
Constables (Matlock Quarries) Ltd. ... 80
Contactor Switchgear, Ltd. 34
Coppee Co. (Gt. Britain) Ltd., The ... 71
Cort, Robert, & Son, Ltd. 78
Counting Instruments Ltd. 15
Cox & Danks, Ltd. ... ... —
Craven Bros. Crane Division, Ltd. ... 3
Crofts (Engineers) Ltd. ... ... 18 & 19
Crooks, L. E. 76
Crossley Bros., Ltd. ... ... —

Davy & United Engineering Co., Ltd. 68
Demag Aktiengesellschaft ... ... —
Dewhurst & Partner, Ltd. 55
D.M.M. Machinery, Ltd. 12
Dyson, J. & J. Ltd. Inside Front Cover

Efco-Edwards Vacuum Metallurgy Ltd. ... ... —
Eimco (Gt. Britain) Ltd. ... ... —
Electroflo Meters Co. Ltd. ... ... —
English Electric Co., Ltd., The 51
English Steel Corporation, Ltd. 40
Evershed & Vignoles Ltd. ... ... —

Foster, Henry, & Co., Ltd. ... ... —
Foster Instrument Co. Ltd. 7
Fraser & Chalmers ... ... —
Fuller's Earth Union Ltd., The ... ... —

General Electric Co., Ltd., The ... 60, 61 & 73
General Refractories, Ltd. ... ... —
Gibbons Brothers, Ltd. 49
Glenboig Union Fire Clay Co., Ltd. ... —
Grant Lyon & Co., Ltd. 4
Green, E., & Son, Ltd. 80
Guest Keen Iron & Steel Co., Ltd. ... 38
Guest, Keen & Nettlefolds, Ltd. ... ... —
G.W.B. Furnaces, Ltd. 32

Hadfields, Ltd. ... ... —
Hallamshire Steel & File Co., Ltd., The ... —
Harland Engineering Co., Ltd. 75
Head, Wrightson, Iron & Steel Works Engineering, Ltd. ... ... —
Head, Wrightson Machine Co., Ltd. 52 & 53
Heywood, S. H. & Co., Ltd. ... ... —
High Speed Steel Alloys Ltd. 74
Holmes, W. C. & Co., Ltd. ... ... —
Holset Engineering Co., Ltd. 63
Honeywell-Controls, Ltd. 54
Howden, James & Co., Ltd. ... ... —
Hudswell Clarke & Co., Ltd. 69
Hunslet Engine Co. Ltd. ... ... —
Huntington, Heberlein & Co. Ltd. ... 39

Igranic Electric Co., Ltd. ... ... —
Ilford, Limited 23
Imperial Chemical Industries Ltd. ... ... —
International Construction Co., Ltd., The 10

Johnson's Rolls Ltd. 21
Johnson Matthey & Co., Ltd. 5

Kestner Evaporator & Engineering Co., Ltd. ... 33
Kingscliffe Insulating Products, Ltd. ... —

Lamberton & Co., Ltd. Outside Back Cover
Lanarkshire Steel Co., Ltd., The 82
Lancashire Steel Manufacturing Co. Ltd. ... 50
Lloyd, F. H., & Co., Ltd. ... ... —
Lodge-Cottrell, Ltd. ... ... —
Loewy Engineering Co. Ltd., The 77
Lysaght's John, Scunthorpe Works Ltd. ... 42

Marshall, Thomas, & Co. (Loxley), Ltd. ... 30
Metropolitan Vickers Electrical Co., Ltd. ... —
Michigan (Gt. Britain) Ltd. ... ... —
Mobil Oil Co. Ltd. ... ... —
Mitchell Engineering Ltd. ... ... —
Mond Nickel Co., Ltd. 28
Moorwood, John M., Ltd. ... ... —
Morgan Crucible Co., Ltd., The ... ... —
Morgan Refractories Ltd. 2
Morgardshammars Mekaniska Verkstads AB —
Moxey, Ltd. ... ... —

National Industries Fuel Efficiency Service ... —
Newalls Insulation Co. Ltd. ... ... —
Newell, Ernest, & Co., Ltd. 66
Newton, Chambers & Co., Ltd. ... ... —

Oughtibridge Silica Firebrick Co. 59

Park Gate Iron & Steel Co., Ltd. ... ... —
Parsons, C. A. & Co., Ltd. ... ... —
Pearson, E. J. & J., Ltd. 72
Pergamon Press Ltd. ... ... —
Phillips Electrical Ltd. ... ... —
Pickford Holland & Co., Ltd. 62
Power-Gas Corporation Ltd., The Inside Back Cover
Press, William & Son, Ltd. 36
Priest Furnaces, Ltd. 35

Rawlplug Co. Ltd., The ... ... —
Richardsons Westgarth & Co. Ltd. ... 29
Roberts, J. W. Ltd. ... ... —
Robertson, W. H. A., & Co., Ltd. 46

Salem Engineering Co., Ltd. ... ... —
Schloemann 45
Shaw, John, & Sons (Salford) Ltd. 74
Shell-Mex & B.P., Ltd. ... ... —
Siemens Edison Swan, Ltd. 25
Simon-Carves, Ltd. 53
Skefko Ball Bearings Co. Ltd., The ... —
Smith, John (Keighley), Ltd. ... ... —
Smith, Thomas & Sons (Rodley) Ltd. ... —
Smith & McLean, Ltd. ... ... —
Stanton Ironworks Co., Ltd., The ... ... —
Steel Co. of Wales, The 13
Stein & Atkinson, Ltd. ... ... —
Stein, John G., & Co., Ltd. ... ... —
Stephens Silica Brick Co., Ltd. 26
Stewarts & Lloyds, Ltd. ... ... —
Stillite Products Ltd. 83
Summerson, Thos., & Sons, Ltd. 79
Sunvic Controls Ltd. 37

Tattersall & Son Ltd. 70
Thermal Syndicate Ltd. 16
Thomas (Richard) & Baldwins, Ltd. ... —
Thornton, B., Ltd. 31

Union Carbide Ltd. ... ... —
United Coke & Chemicals Co. Ltd. ... 78
United Steel Companies Ltd. 70

Vaughan, Edgar, & Co., Ltd. ... ... —
Visco Engineering Co., Ltd. 81

Wallsend Slipway and Engineering Co. Ltd. ... —
Ward, Thos., W., Ltd. 8
Warner & Co., Ltd. ... ... —
Wellman Bibby Co. Ltd. 52
Wellman Smith Owen Engineering Corporation Ltd., The 1
West Hunwick Silica & Firebrick Co., Ltd. —
Whitehead Iron & Steel Co., Ltd. 20
Wiggin, Henry, & Co., Ltd. ... ... —
Wild Barfield Electric Furnaces Ltd. ... —
Willan, G. L. Ltd. 22
Wincott, G. P., Ltd. 14
Woodall-Duckham Construction Co., Ltd. 6

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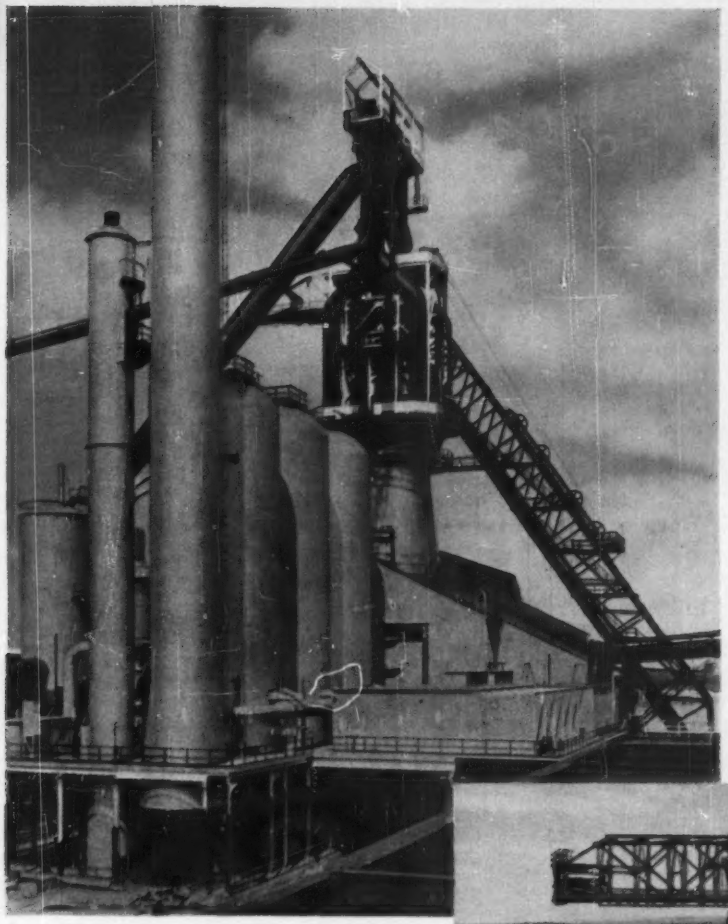

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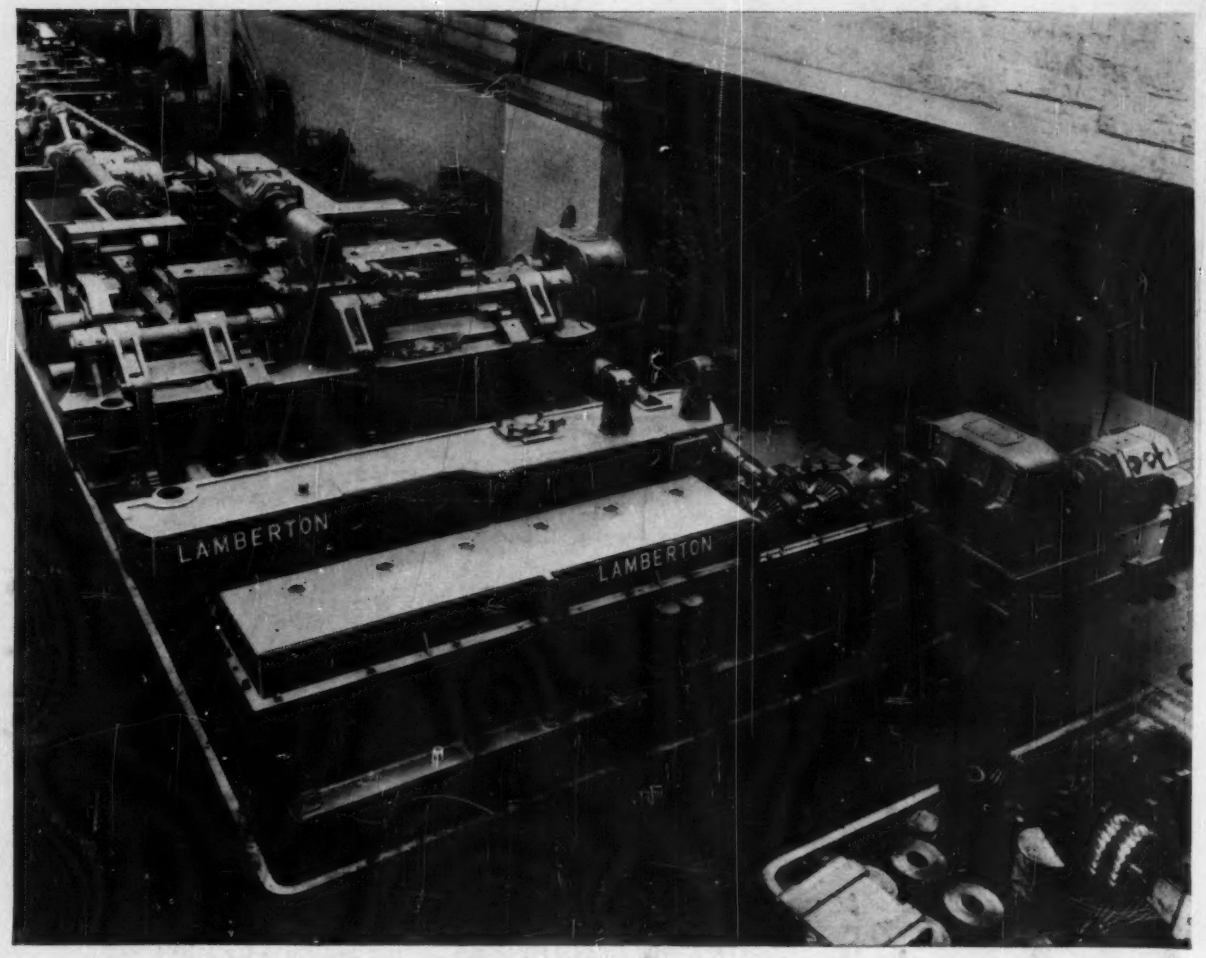

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